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The Wash Sprat Fishery

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Errata slip

Abstract (p.vii), eighth para, first line: for L_{oo} read L_{∞}

Page 7, second para, last line: for a typical read atypical

Page 49, first para, third line, and second para, third line: for $L_{\infty c}$ read L_{∞}

Page 59, second para, lines 12, 15 and 18, for $L_{\infty c}$ read L_{∞}

Page 76. Reference to Carruthers J. N. 1929, second line: Fishery Invest., Lond. should be in italics.

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ABSTRACT

The Wash sprat fishery recommenced early in 1959 after a lapse of thirty years. This followed an exploratory voyage made in December 1958 by a Ministry research vessel to locate new sprat stocks for exploitation by the Thames Estuary sprat fishermen, who had suffered a collapse in their own fishery since 1956.

The Wash fishery has been studied in detail since its resumption, and the results of the first ten seasons are presented in this paper. These investigations have involved the collection of catch-data and samples of fish from the commercial fishery, supplemented by echo and fishing surveys carried out by research vessels.

During this period there has been an overall increase in total effort and catch, and the character of the fishery has changed from a relatively small-scale affair involving small (35–40 feet) pair-boats, fishing primarily for canning and petfood outlets, to a larger-scale fishery mainly undertaken by bigger (50–60 feet) seiner-type vessels fishing as single-boat midwater trawlers for meal and oil reduction purposes.

The seasonal pattern of the fishery has shown minor variations, principally in time of commencement, but generally it reaches a good productive level by the last week of November and maintains this until February, when a fairly rapid decline usually results in its termination by early March.

The fishery is dependent on the fish aggregating in fairly localized and stable high-density patches which, once formed, can maintain their identity for most of the season. Echo surveys have shown that the positions of these are in much the same topographical locations each season, irrespective of differences or changes in the temperature and salinity patterns. In some seasons these patches have shown localized movements, and towards the end of the season have generally shown an offshore shift before breaking up or becoming too scattered for economic exploitation. There was no relationship evident between the timing and duration of the fishery and temperature or salinity values.

In most seasons two- and three-year-old fish clearly predominated in the catch, constituting on average nearly 80 per cent by weight. Even in the first season, fish older than three years were generally scarce, which could be primarily due to emigration loss offshore. This is thus basically a recruit fishery and is very dependent on the strength of the recruiting brood in each season. Very large year-classes can support the fishery when two and three years old, but medium or small ones only make a significant contribution when two years old. The very large broods can also make a fairly large contribution to the catch in their first year, although only the larger members are then caught.

There is a considerable overlap between the length distributions of successive age-groups, probably mainly due to the extended spawning period providing a wide time-base for the commencement of development. There is also a possible 'carry-over' of late-spawned fish into the following year-class, due to their being too small to lay down a recognizable winter otolith ring in their first winter.

An average growth pattern and the associated parameters were established (L_{∞} 13.2 cm; K 0.53), but these cannot be taken as valid for the entire population, due to incomplete representation at the lower and upper ends of the age-scale. The possibility of density-dependent influences on growth was also examined and although available data on growth in the first year were inadequate for this purpose there was some indication of these effects in second-year fish.

The strength of recruitment of year-classes was examined in relation to growth within, and size of, the parental stock. There was some evidence for a proportional relationship between the sizes of year-classes and parental stock, and less clearly established relationships with growth in the parental stock.

An analysis of mortalities produced very variable results, these being caused by factors of partial recruitment, emigration loss and saturation fishing at high stock densities. Average values indicated a numerical loss of just over 50 per cent between the ages of two and three years, increasing to over 80 per cent between three and four years.

A closely proportional relationship was established between total catch and total effort, implying that the fishery has had no measurable effect on the total yield of the stock, and since it is essentially a recruit fishery this could only happen when effort attained a level directly influencing the strength of recruitment.

However, when the effect of increasing effort on the yield of individual year-classes after recruitment was examined there was some indication of a reduction in the yield of four- and five-year-old fish in more recent seasons.

A maturity scale was constructed based entirely on macroscopic appearances and fish were staged according to this. Most fish remain in early stages of maturity until February, when the first signs of more active development appear in the majority of the population. This coincides with the period when the overwintering concentrations begin to break up and disperse, although even at the end of the fishing season (March) very few fish in spawning condition have been recorded. (Egg surveys show that spawning is usually well-established in this region by April).

There was some evidence for larger fish developing more rapidly than smaller ones, and the minimum size for maturation lay between 7.3 and 7.9 cm in most seasons. However, the 1967–68 season, with its above-average numbers of first-year fish, proved a notable exception and provided sufficient data to show that both sex and age can have some influence on the minimum size for maturation.

INTRODUCTION

The Thames Estuary has for many years been a traditional source of sprats in England. Formerly the fishery used stownet gear—fixed nets attached to the vessel's anchor chain, utilizing the strong tidal currents in the area to carry fish into them. In the early 1950s this gear was rapidly superseded by a new method of sprat fishing, pioneered in this region by the Leggatt Brothers of Whitstable. This was pair-boat midwater trawling, using echo sounders to locate the fish shoals; it proved very successful, and by 1955 some 22 pairs were working in the estuary. Catches increased between 1950 and 1955, but in the 1956–57 season there was a marked decline which became worse in subsequent seasons, causing the fishery to become unprofitable.

In 1958 the Ministry of Agriculture, Fisheries and Food were asked to look into the possibility of locating new stocks for the Thames fishermen. It was decided to investigate the potentialities of the Wash area, since there were various pointers leading to it:

(1) historical evidence of old-established sprat fisheries in the region;
(2) some statistical returns from a sprat fishery there between 1906 and 1929;
(3) reports in recent years that shrimp fishermen had often caught considerable quantities of sprats in their shrimp trawls.

Furthermore the area was close enough to the Thames Estuary to attract the fishermen, as well as being a relatively sheltered region suitable for small boats of about 40 feet in length, and there were three accessible ports: Boston, King's Lynn and Wells.

THE HISTORICAL BACKGROUND

The Minutes of Evidence from the Sea Fisheries Commission Report of 1866 (Anon. 1866) give some indication of the extent of sprat fishing in the Wash area at about that time. At King's Lynn in 1853 there were 4 or 5 vessels stownetting for sprats, in 1860 7 to 9 and in 1863 10 to 12 boats. The stownet season usually extended from November to March, in the latter month the fish leaving the Lynn Deeps and moving seawards. In a good season catches of 4-5 tons of sprats per voyage were not uncommon, and in a ten weeks' season a single vessel could land a total of 40 tons. The total catch landed at King's Lynn then averaged about 160 tons per season. About half the season's catch was disposed of as manure for local farmers at prices ranging between 14s. 6d. and 18s. 0d. per ton, the rest going mainly to the fresh market at prices ranging between £5 and £20 per ton, depending on supply and demand. On average, the vessels earned between £2 and £4 per week during the season. At times the nets would take entirely sprats and at other times large numbers of small herrings mixed with them. Mature herrings were also caught in a 'full' condition between December and January; they were 'shorter and deeper in the body than the deep sea fish.'

In addition to stownets another type of gear—termed a 'trim-net'—was also extensively used, but this was set mainly in the creeks and rivers, catching a variety of species such as smelts, eels, flounders, whitebait and sprats. This net has a triangular opening with a lower spar some 22 feet long and side spars 18 feet in length; it was of considerable antiquity and there were records showing that it had been employed in the region at least since 664 A.D.

The sprat landings for the Wash area over the period 1906–1929 show that the fishery was then only a

relatively small-scale affair, with an average seasonal catch of just over 100 tons. The fishery gradually faded out in the economic depression of the twenties with its resulting lack of markets.

The first survey was made by the Ministry's research vessel ONAWAY between 4 and 8 December 1958. This showed good concentrations of sprats in the Wash area, and the information was published in a Laboratory Leaflet which was circularized to the Thames fishermen. The first commercial landings were made at King's Lynn just after Christmas by two pairs from Whitstable (who had previously been working from Lowestoft on the local sprats, but these rarely concentrate enough to make trawling a profitable venture). Early in the New Year several other Thames pairs established themselves at Boston, whilst the first two pairs transferred to Wells on the north Norfolk coast. Examples of these small pair-boats are shown in Plates 1 and 2.

This first season lasted for two months during which eight pairs of vessels participated, landing a total of 1 190 tons, a good proportion of which were at first taken for canning, but later in the season most were used for petfood. Since then there have been nine more successful seasons, during which the constitution of the fleet engaged in the fishery has changed somewhat. Up to the 1962–63 season the major effort was contributed by pair-boats of Thames origin, with a few local pairs from Boston. During the 1961-62 season the Thames fishery began to show a marked improvement and then built up to a high level in the following three seasons. This resulted in the loss of most of the Thames component of the Wash fleet, especially in the 1963–64 and 1964–65 seasons. However, this latter period saw the entry of somewhat larger (50–60 foot) Grimsby-based seiner-type vessels (Plate 3) on a large scale. These fish mainly as single-boat midwater trawlers and have in recent seasons been responsible for the major part of the Wash catch, most of their landings being used for fish-meal (Plate 4).

GENERAL DESCRIPTION OF PAIR-BOATS, THEIR GEAR AND METHOD OF FISHING

These vessels show a considerable variety in structure and form, although essentially those which are based in the Thames and the Wash are 35–45 feet in length, with engine ratings of between 30 and 60 hp, and employ four to six crew members per pair. The trawls used are based on the Larsen midwater trawl in general design, being constructed of four panels of netting, forming a gradually tapering funnel of square section leading to a long tubular cod-end. Four short corner 'wings' provide the towing point attachments. The dimensions of a typical net show an aperture measuring 36 by 36 feet and an overall length of 180 feet, of which 60 feet or so is made up of cod-end lengthening pieces. The headline is supported by 6–8 spherical floats and each lower wing is weighted by a heavy metal block (about 75 lb) attached by a short length of chain. The mesh size commences at about 2-inch (5-cm) bar in the entry and decreases to 1 inch (2.5 cm) near the cod-end, the cod-end and cod-end lengthening pieces having a mesh of about $\frac{3}{8}$-inch bar (10 mm).

When a good shoal of fish has been located the vessels proceed downtide to a point beyond the shoal and then turn into the tide to shoot towards the fish. The leader boat streams out the net as far as the wings, shooting then being completed when the partner's wings have been passed across and shackled on to their warps. The warps are then run out, the vessels meantime gradually drawing away from each other The length of warp to be run out will depend on the depth of the shoal, the lower warps requiring a relatively greater length of warp to balance the net correctly in the water. Decisions as to the actual length of warps to be let away in a given set of circumstances are usually derived from 'rule of thumb' calculations which have been endorsed by long experience.

The distance apart of the vessels varies, depending to some extent on the length of warp out, but changing this spacing can also alter the fishing depth of the net without shortening or lengthening the warps. When they converge the vessels pull more directly ahead, and this results in an increase in speed, which raises the level of the net. Changing engine speed can also be used to adjust the net level. A large 'buff' is usually connected to the end of the net by a long enough rope to enable it to float at the surface during towing operations. This buff acts as a marker to other vessels in the vicinity and also gives warning when the net becomes overfull, by being pulled below the surface. The towing speed of the vessels is usually between $1\frac{1}{2}$ and 2 knots through the water, which is very turbid in this region.

These boats fish almost entirely during daylight hours, and the average time spent towing may vary from only 15 minutes when the fish are very densely aggregated to 2 or 3 hours when they are more widely dispersed. The usual duration of a tow varies between 30 minutes and 1 hour, the length of time depending on the trace density recorded by the echo sounder. If the vessels tow out of a patch of fish it is often quicker in the long run to haul the gear and then search briefly at speed to relocate the shoal before shooting again.

Fishing is conducted on a daily basis, ideally leaving port early in the morning with usually a 2–3 hour steam to the fishing area, followed by 2–3 hours actually fishing, and a return by late afternoon or early evening. However, it is not always possible to follow such an idealized routine, since the ports from which the vessels work (principally Boston and Wells) show a considerable tidal range and have very shallow approach channels. It is thus only possible to make a safe passage between about half-tide and high water, this tending to restrict fishing time to some extent. The boats also try to utilize as far as possible the strong tidal currents to assist them in their passage from port to grounds, since from either Boston or Wells a minimum steaming distance of some 15–20 miles is involved to reach the Lynn Deeps where the fishing commonly takes place.

This daily basis of working and tidal limitations on operations means that these small pair-boats have a limited working range within which they can be sure of allowing sufficient time for successful fishing operations and a return to catch the tide at their base port. Thus in some earlier seasons, when fishing effort was limited, there were often occasions when good concentrations of fish were located on research

vessel echo surveys well outside the working range of the smaller craft. An example of this occurred in 1961–62, when a large concentration was located near the southern end of the Inner Silver Pit, but remained entirely unexploited throughout the season. However, there are usually more than enough fish nearer home to provide good fishing. These factors do not apply to the larger (50–60 foot) Grimsby-based seiner-type vessels which have entered the fishery since 1963–64. These boats fish mainly as single-boat midwater trawlers and have in recent seasons been responsible for the major part of the Wash catch; they can stay out for as long as it takes to make a paying load, and are also able to work under more extreme weather conditions.

When up to ten pairs are working, each vessel equipped with an echo sounder which may be run continuously during steaming time, it does not normally take long for the fleet to locate a fishable concentration, and often on any one day the boats will tend to aggregate and fish within quite a limited area. The less experienced crews usually follow the more experienced ones and shoot nearby. Searching time is generally minimal due to the fact that the fish tend to concentrate in a particular, fairly local, area for a considerable part of the season, and within this general area more densely aggregated patches may persist for a week or more.

After the season has become established, the fishermen thus have some foreknowledge of the most likely area to work on a given day, after making allowance for tidal displacement of the fish. Tidal movement is considerable in the Wash region, the 'tidal fetch' on spring tides being up to 7 nautical miles and on neap tides about 4 nautical miles, and as the fish tend to move more or less passively with the tide, both fish and fishing may shift from day to day.

DEVELOPMENT OF THE FISHERY, 1958-1968

TRENDS IN TOTAL CATCH

A general seasonal analysis of the total number of landings, total catch, mean catch per landing, catch per unit effort and mean fishing (net in the water) time per trip is shown in Table 1. The data are grouped for the smaller pair-boats working from Boston and Wells, and for the larger Grimsby vessels working singly and in pairs. These larger boats are normally engaged in seining for most of the year, but as the winter period is usually a difficult one for this work they have changed over to midwater trawling for sprats. The main outlet for their catches has been to the fish-meal plants at Grimsby, but as the prices for meal are considerably less than those for other markets—such as canning, fresh sale or petfood—larger quantities of fish per trip are necessary to make it an economic proposition.

The pattern of development of the fishery over the period 1958–1968 is shown in Figure 1A, in terms of total catch by seasons for all types of vessel and also independently for the two main classes (the smaller pair-boats and the larger Grimsby vessels). In the first four seasons the fishery was almost entirely supported by the small pair-boats, mainly of Thames origin with a few local pairs from Boston. In 1962–63 most of this effort was withdrawn from the Wash when the Thames fishery showed a marked improvement, but this loss was compensated for to some extent by the entry of two pairs of larger Grimsby vessels. Up to this time the catch had averaged about 2 000 tons per season, most of it being used for canning and petfood. The Grimsby effort increased considerably over the next few seasons and was soon responsible for the major part of the catch (Table 2). The smaller pair-boats did not make a significant contribution again until the 1967–68 season, when a number of Thames vessels returned to the Wash to participate after the failure of their own fishery. In the 1967–68 season nearly all the catch of about 8 000 tons went for meal and oil reduction and very little to other outlets such as canning, petfood and for sale fresh. A more detailed season by season analysis of the fishery is presented in the Appendix Tables.

The fishery has shown a general up-trend in total catch which is very closely related to effort, as shown in Figure 1B. In this instance the total catch by both types of vessel has been divided by the catch per unit effort of 40-foot pair-boats to give a standardized measure of effort. The slope of the regression is proportional to the mean catch per unit effort over this period. The exceptional nature of the 1967–68 season, with a catch per effort about three times greater than the previous average, produced a value well outside the range of earlier observations; it is shown as an open circle in this figure, but is not included in the calculation of the regression.

Over the period 1958–1967 the catch per landing by the 40-foot pair-boats has been maintained at around 5–6 tons per landing, despite the catch per hour's fishing having fluctuated by a factor of about four times between seasons. The efficiency of the Grimsby vessels has generally been considerably less (in terms of catch per hour) than that of the smaller pair-boats, due partly to inexperience and also to the fact that most of them have worked as single-boat trawlers—a basically less efficient method of midwater trawling than that of a pair of vessels employing the same type of net. The general order of difference in the catching power of the pairs compared with that of single boats is between three and four times (Appendix Table C). However, the Grimsby boats fish for much longer periods, and can stay out (weather permitting) as long as is needed to make an economic catch.

In order to understand the variations involved within and between seasons a more detailed study of the fishery has been made with the aid of special landing forms devised for the smaller boats. These forms were distributed to part-time collectors, who arranged for them to be completed by co-operative skippers, one form being submitted for each voyage made. This scheme came into operation in the 1959–60 season, and although coverage has varied (depending on the degree of co-operation) it has included a high proportion of the landings in most seasons.

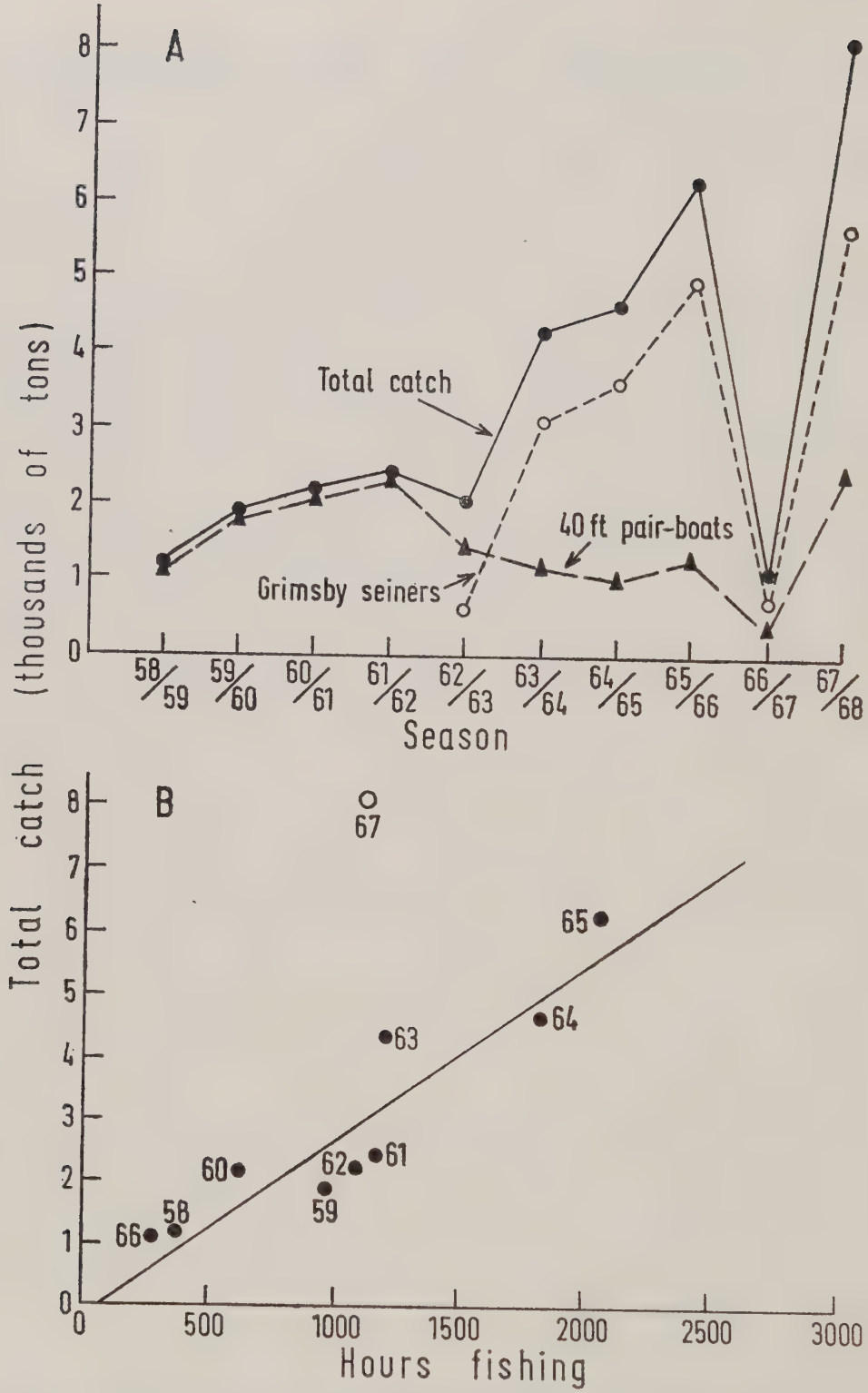


Figure 1 Trends in the development of the Wash sprat fishery from 1958 to 1967:
A, as catch by 40-foot pair-boats and by Grimsby seiners, and as total catch by both types of vessel.
B, as total catch related to fishing effort (effort by both types of vessel converted to standard measure of effort ≡ hours fishing by 40-foot pair-boats). The point for 1967 is excluded from the regression (see text).

THE SEASONAL PATTERN OF THE FISHERY

Appendix Table D gives a detailed breakdown on a monthly basis for the Wash sprat landings, showing the trends of catch per landing and catch per hour in each season for the 40-foot pair-boats and the Grimsby vessels. The 'shape' of each season has varied somewhat, with peak months falling at any time between November and February. The 1966–67 season was rather different from the others in two respects: the Grimsby vessels participated only for the first two months and then left the area to fish off North Shields, and severe weather ended the fishery prematurely in February. The final season, 1967–68, was also exceptional, in that a very high catch per unit effort was recorded for both types of vessel.

The average pattern of the Wash fishery for the 1958–1967 seasons for each of the classes of vessel participating is given in Figure 2. The left-hand figures express it in terms of total catch and total effort (number of landings) in each month, whilst the right-hand ones give it in terms of the average catch per unit effort (tons per hour's fishing) and catch per landing (tons) by months. Catch and effort parallel each other fairly closely for all types of vessel, as do catch per unit effort and catch per landing, but there are differences in the average seasonal picture presented by the different types of fishing unit. These are due mainly to the relatively shorter time periods involved for the Grimsby boats, particularly the Grimsby pairs, in that they only seriously participated for a few seasons, and also tended to exert their main effort somewhat later in the season. Since the 40-foot pair-boats cover a longer time period they probably give a better average estimate of changes in the fishery within a season. They show, in terms of catch per hour and catch per landing, a clear peak in November, a slight dip in December and a further peak in January to February, with subsequent rapid decline. A similar pattern is shown for the Grimsby single-boat midwater trawlers, but a rather exaggerated and a typical picture emerges for the Grimsby pair-boats.

The differences in the trends of catch per hour in each season between the smaller pairs and the Grimsby boats have arisen mainly from the differences in the areas worked by the two classes of vessel. In 1963–64, for example, the Grimsby peak in February represented a period of intense fishing on a very localized concentration of fish in the Humber Estuary, and there has been a tendency, particularly later in each season, for the Grimsby boats to fish more off the Lincolnshire coast and also in the Inner Silver Pit areas, which are beyond the normal range of the smaller boats. However, in 1965–66 both types of vessel fished in much the same general area for most of the season, and their catches show a close similarity in trends.

For the 40-foot pair-boats the relationship between catch per hour and catch per landing has changed somewhat over the period under review. Up to 1963–64 these two values mirrored each other fairly closely, total fishing time remaining fairly constant throughout the season, but since the fish-meal market has become the main outlet fishing time has tended to adjust to the prevailing catch per unit effort in order to maintain the catch per landing as high as possible. This has sometimes resulted (as in the 1964–65 season) in an increasing catch per landing with decreasing catch per unit effort. The Grimsby vessels have a much greater latitude in the time they can spend at sea, and hence the relationship between catch per hour and catch per landing has been more variable.

To sum up, it may be said that on average the fishery has reached a good productive level by November (usually late in the month), maintained this level until January, and shown signs of decline in February and a marked falling-off in March, the season usually ending that month.

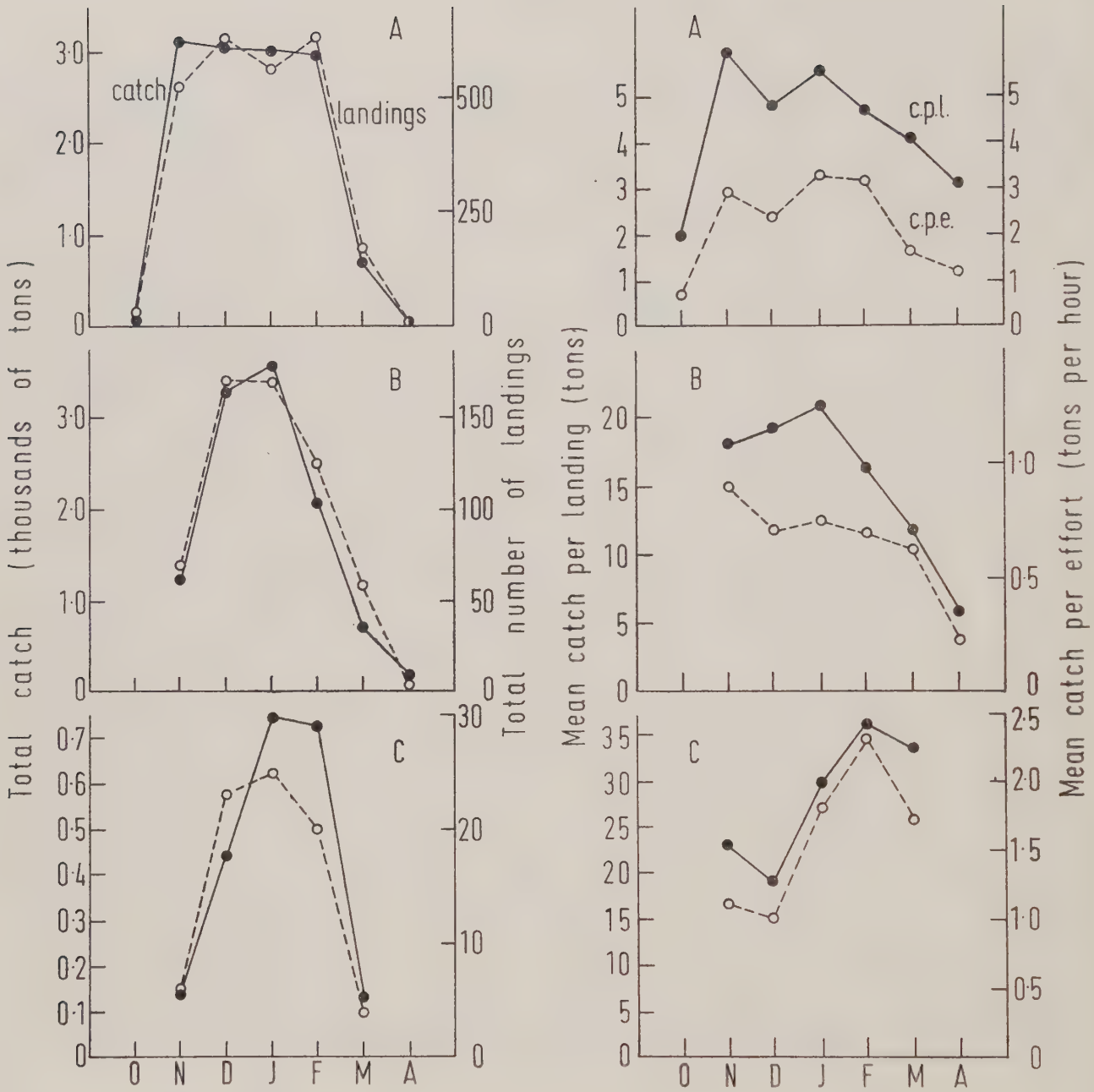


Figure 2 The average pattern of the Wash sprat fishery over the period 1958–1966:
A, 40-foot pair-boats, 1958–1966;
B, Grimsby single-boats, 1963–1966;
C, Grimsby pair-boats, 1962–1965.

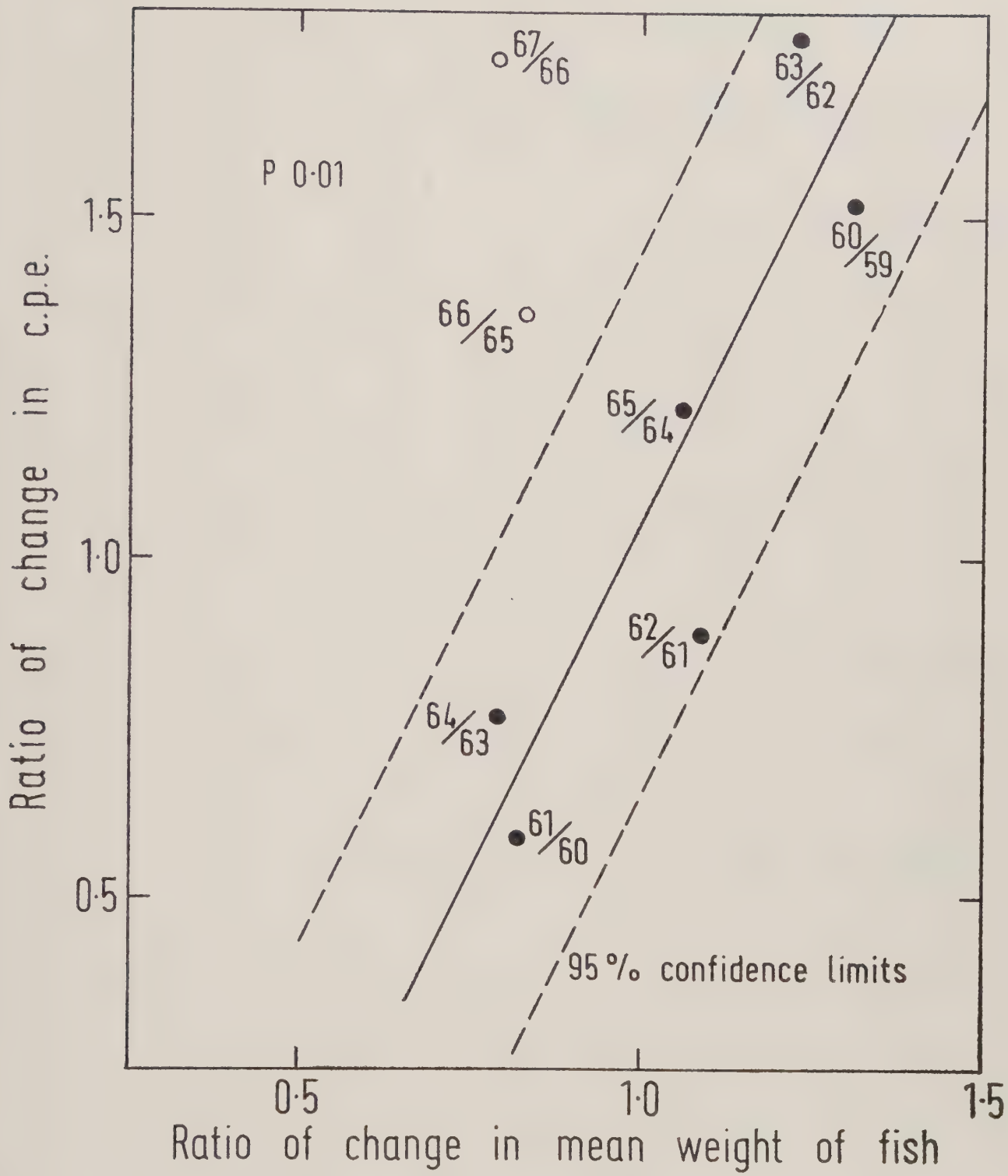


Figure 3 The relationship between the change in catch per unit effort, by weight, and the change in the mean weight of fish between successive seasons.

Table 1 Seasonal analysis of the Wash sprat fishery

	Season	Number of landings	Total catch (tons)	Catch per hour (tons)	Catch per landing† (tons)	Mean fishing time per tripø (hours)
Boston and Wells	1958–59	248	1 190	–	4.80	–
(40 foot pair-boats)	1959–60	463	1 814	2.30	3.90	1.7
	1960–61	415	2 184	3.50	5.25	1.5
	1961–62	488	2 437	2.07	5.00	2.4
	1962–63	328	1 426	1.85	4.35	2.3
	1963–64	205	1 185	3.25	5.80	1.6
	1964–65	137	1 009	2.50	7.35	2.9
	1965–66	191	1 269	3.05	6.65	2.2
	1966–67	71	404	4.15	5.70	1.4
	1967–68	252	2 468	7.17	9.80	1.4
Grimsby seiners						
(i) pair-trawl	1959–60*	11	75	2.00	6.85	3.5
	1962–63	26	486	1.75	18.65	10.6
	1963–64	25	867	2.03	34.70	17.0
	1964–65	19	543	0.72	28.60	39.4
	1965–66	8	283	1.07	35.35	33.0
(ii) single-boat	1962–63	7	113	1.10	16.10	14.6
midwater trawl	1963–64	130	2 248	0.80	17.30	21.6
	1964–65	194	3 101	0.27	16.00	34.1
	1965–66	224	4 708	0.91	21.00	23.0
	1966–67	44	742	0.41	16.85	41.0
	1967–68	205	5 635	2.63	27.50	10.4

* Hull seiners—one pair fished experimentally during this season.
† For pair-trawlers a landing represents the effort for one pair-boat unit (i.e. two vessels).
ø Actual time of the net in the water.

TRENDS AND CHANGES IN THE FISHERY

The main trend over this ten-year period has been one of increasing effort and catch, the parallel movement of these showing that the level of effort imposed by the fishery to date has not had any measurable effect on the stock. This is confirmed by Table 3 which shows no relationship between catch per unit effort and total standardized effort in each season. There is no clear trend in catch per unit effort, although it has tended to increase slightly over the last few seasons.

The weight index of catch per unit effort used here is a function of the numerical rate of capture and the mean weight of the individual fish. In most seasons a particular age-group has predominated (usually two- or three-year-olds), and although the numerical index of catch per unit effort may not change a great deal between seasons the weight index may register a larger change if the average weight of fish in the catch alters from basically that of a two-year-old to one of a three-year-old, or vice versa. A relationship of this type is evident over the seasons 1959–60 to 1965–66, and this is shown in Figure 3, where the ratio of change in catch per unit effort, by weight, between successive seasons is plotted against the ratio of change in the mean weight of fish between the same seasons. This implies that over this period differences in catch per unit effort by weight between seasons were mainly due to changes in the mean weight of individual fish in the catch. The ratios between the final three seasons (shown by open circles in Figure 3) fall outside the range of the earlier observations, and when these are included in the regression analysis the relationship becomes non-significant. Certain features of the last two seasons were responsible for this divergence from the earlier pattern. For example, in the 1966–67 season three-year-old fish predominated, but these were very small for their age, and in fact their average weight was less than in the previous season when they were two-year-olds. The 1967–68 season was outstandingly different from all the others in that large first-year fish predominated, which reduced the average weight of fish in the catch, but this was more than compensated for by the very high numerical rate of capture.

In the more recent seasons there has been a tendency for a later start (last week in November) than in the earlier ones. Furthermore, the 40-foot pairs have shown a shorter season, ending the fishery in February, due to the reduced size of this component of the fleet, and also to weather and economic factors. The March fishery was generally rather limited and took place mainly within the first half of the month, and often involved steaming long distances to locate fishable concentrations. The Grimsby vessels have had an advantage in end-of-season fishing because of their longer range and duration, and have thus been able to continue working until the catch-rate became uneconomically low. For both types of vessel alternative forms of fishing sometimes offer a more profitable prospect and this can result in an abrupt end to the sprat fishery.

A fishery of this type, showing a low average age of fish in the catch (2.5 years), is very dependent in each season on the strength of the recruiting year-class, and only very strong broods can support the fishery in two successive seasons. The age of nearly full recruitment on a length basis can be taken as two years. There is also evidence for an emigration loss to deeper water offshore of the larger and older fish, which can sometimes be very apparent by three years of age (e.g. in the 1966–67 season); this results in a marked decline in numbers of fish beyond this age, with only the smaller element of these remaining in the fishery. It is significant that the first season (1958–59) produced very few fish beyond the age of three years, even though the stock had then been unexploited for thirty years.

The fishery is thus taking place almost entirely on recruit stock, and in this situation fishing effort can only seriously affect the population if it reaches a level directly influencing the relationship between stock and recruitment. The size of the total spawning stock supporting this fishery is not known and therefore the effect of fishing mortality on it cannot be estimated.

Table 2 The total Wash sprat catch in the years 1958 to 1967, and the percentage taken by Grimsby vessels

Season	Total catch (thousand tons)	% taken by Grimsby vessels	Maximum number of Grimsby vessels	
			Pairs	Singles
1958–59	1.2	–	–	–
1959–60	1.9	4.0*	1*	–
1960–61	2.2	–	–	–
1961–62	2.4	–	–	–
1962–63	2.0	27.8	2	1
1963–64	4.3	72.4	1	7
1964–65	4.7	78.3	2	15
1965–66	6.3	79.7	2	22
1966–67	1.1	65.6	–	16
1967–68	8.1	69.5	–	19

* One pair of Hull seiners fished experimentally.

Table 3 Summary of the increase in catch in relation to fishing effort

Season	Total effort (≡ hours fishing by 40 foot pair-boats	Total catch (tons)	Catch per effort (tons/hour)
1958–59	(372)*	1 190	3.20
1959–60	966	1 889	1.95
1960–61	623	2 184	3.50
1961–62	1 176	2 437	2.05
1962–63	1 095	2 024	1.85
1963–64	1 213	4 300	3.55
1964–65	1 861	4 653	2.50
1965–66	2 052	6 259	3.05
1966–67	276	1 146	4.15
1967–68	1 129	8 103	7.15
Means	1 076	3 417	3.15

* Calculated value.

GENERAL DESCRIPTION OF THE WASH AREA

TOPOGRAPHY AND HYDROGRAPHY; THE LOCATION OF THE OVERWINTERING SPRAT CONCENTRATIONS

A general topographical view of the Wash covering the main fishing areas is shown in the Frontispiece, the various regions being named according to their associated channels, buoys, banks and lightvessels.

A well-defined deeper-water channel (>10 fathoms) extends from the south end of the Inner Silver Pit (about 15 miles off the Lincolnshire coast) to the extreme south-west end of the Wash, covering a total distance of some 30 nautical miles. It is about 5–6 miles wide at its northern end and gradually narrows to only 2–3 miles across at its south-western end. Westwards lies an extensive area of shallower water off the Lincolnshire coast with an average low-water spring tide (LWS) depth of 5–6 fathoms, being about 5 miles wide at its southern end and increasing to about 15 miles wide at its northern end near the Humber entrance. On the eastern side is a triangular-shaped wedge of banks and shallow water off the north Norfolk coast, which extends at its apex to about 15 miles off the coast and provides some measure of shelter to the channel in this region. Deeper water within the land-bounded part of the Wash Estuary is rather limited, since half this region dries out at low water of spring tides.

The main sprat concentrations have been found within or along the edges of the channel between the Inner Dowsing and Roaring Middle, the area of the potential fishing ground covering some 160 square nautical miles, with an average water depth of 9–10 fathoms (LWS) and a maximum depth of 25–30 fathoms in the Lynn Well.

The area is subject to strong tidal streams, often showing complexities of direction and phasing, especially near the banks and over the shallows, although basically the main tidal axis follows that of the principal deeper-water channel.

Not a great deal is known about the residual current systems in the Wash area, but evidence derived from the movement of bottom and surface drifters, current measurements and study of the bottom topography (Carruthers 1926, 1929; Ramster 1963; Robinson 1964) indicates that 15–20 miles offshore from the Wash (clear of the inner banks and shallows) the predominant residual direction of water movement is that of the main central North Sea anti-clockwise swirl south of the Dogger, moving easterly at an average rate of about 1 mile per day. Closer inshore this system forks in the vicinity of the Inner Silver Pit, and between the Inner Dowsing and Dudgeon shoals, to become involved in a very complex circulation pattern near the coast. A north-going residual is evident in the vicinity of the Inner Dowsing shoal, whilst near the Lincolnshire coast, apart from a few local circulation cells, the general direction of residual movement is from north to south. The main Wash Channel seems predominantly a flood system with indications of outflow in the shallow marginal areas. Immediately offshore (up to 5–10 miles) from the north Norfolk coast, between Blakeney and Burnham Flats, an east to west residual predominates, but further out the reverse occurs. A tentative picture of the circulation pattern derived from the available evidence is shown in Figure 4, together with the three main and five subsidiary concentration areas for sprat.

The complexity and strength of the tidal streams in this area ensure almost complete mixing of the water column; hence no significant vertical stratifications of temperature or salinity have been recorded within the areas of fish aggregation. However, there are frequently marked horizontal gradients of temperature and salinity, particularly after periods of high freshwater run-off (usually maximal between January and March). Four main river systems (Witham, Welland, Nene and Ouse) drain into the Inner Wash and between them cover a large catchment area, but their discharge is usually strictly controlled by a system of sluices and pumping stations. Their influence on the coastal water is thus only really noticeable after flood or near flood conditions, and even then the outflow is not very evident along the main deeper water channel, but tends to be confined to the shallower marginal areas of the Inner Wash. The main influence

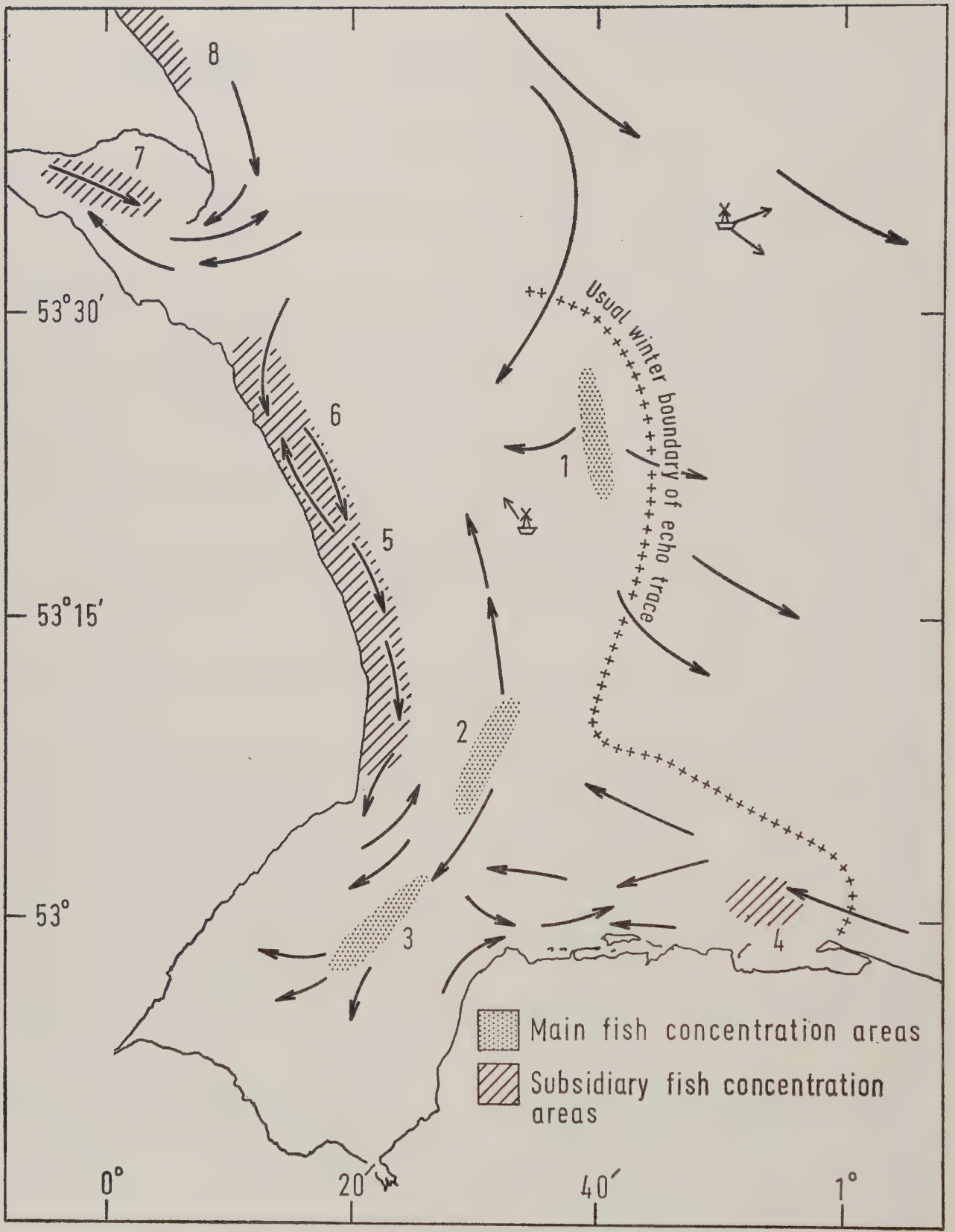


Figure 4 The residual current movements in the Wash area, and the areas of the main and subsidiary sprat concentrations.

on coastal water conditions to the north is the outflow from the Humber Estuary, which trends south over the Lincolnshire coastal shallows where it may mix with water from the north side of the Wash to form a 'bulge' of lower salinity covering this region. The main Wash Channel usually contains relatively higher-salinity water, particularly towards its southern end where a 'wedge' of more saline water is often found extending across the entrance to the land-bounded part of the estuary.

Evidence from echo surveys and the distribution of fishing effort has shown a remarkable degree of constancy in the main concentration areas of sprat in each season; these seem to relate more closely to the topography of the region than to temperature or salinity patterns.

The most frequent loci for the initial formation of concentrations have been towards the southern end of the Inner Silver Pit (position 1 in Figure 4), between the south Inner Dowsing and Lynn Knock (2), and Lynn Well to the Roaring Middle (3). A less frequent locale is found off Wells between Stiffkey and Blakeney Overfalls (4), whilst later in the season, after the main channel patches have dispersed, the Lincolnshire coast (5 and 6) has in some years provided a profitable ground. Occasionally the Humber Estuary (7) and Yorkshire coast (8) up to Bridlington Bay have supported fisheries at the end of the season (February–March).

The sprats usually first show signs of aggregation along the main deeper-water channel during November, when the water temperature is falling most rapidly (from around 11 °C at the beginning to 7 °C at the end of the month), and when the salinity (although this is much more variable) is generally only just beginning to decrease and still relatively high (33.5–34.0‰). The winter concentrations normally commence dispersing in the latter half of February and early March, when temperatures are minimal (around 4 °C) or just beginning to show a slight increase, and salinities are also near their minimum (32.9–33.0‰).

During the winter months there is a fairly clear-cut boundary between the presence and absence of pelagic fish traces, this being particularly marked off the north Norfolk coast between the Race Channel (where traces have been almost entirely absent) and the Burnham Flats Channel nearer the coast. This boundary coincides approximately with that of the change in direction of the predominant drift patterns, and here the fish are within a water system keeping them in the vicinity of the Wash Estuary. In general terms the pattern of water circulation, as far as it is known, is favourable for transporting fish into the estuary from offshore and maintaining them there within a relatively close circulation system (over a period they show little positive activity).

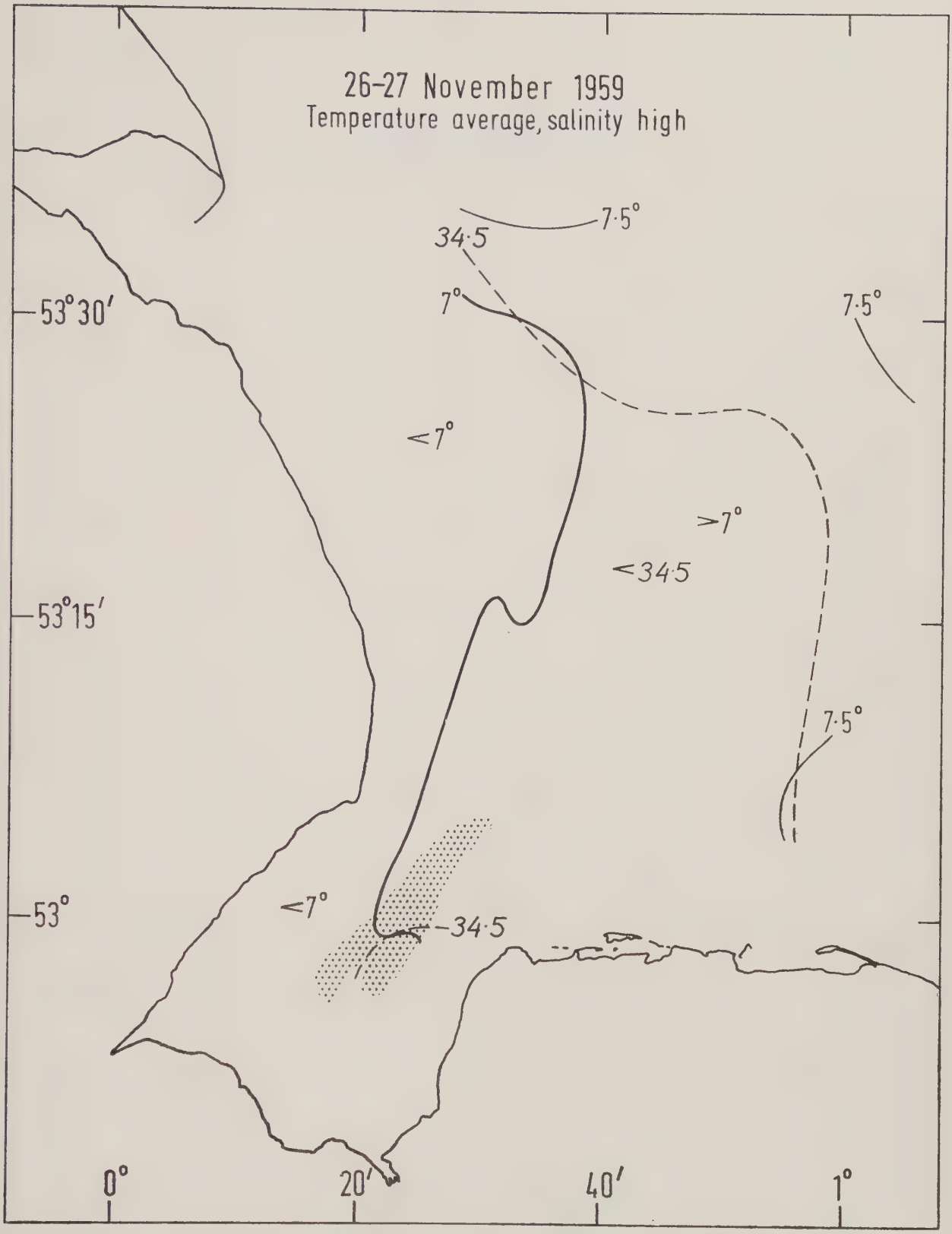
The fish concentration areas are usually very distinct, with fairly clearly defined boundaries, and by using echo sounding techniques the shape and position of these patches can be plotted. The effects of tidal distortion are eliminated by a computer programme reducing all the original positional observations to a common state of tide corresponding with the moon's meridional passage at Greenwich. In this area the positions of the corrected observations fall near their low-water positions, thus placing them near their extreme shift to seawards within the main channel.

In Figures 5–9 is shown a series of charts which illustrate temperature and salinity patterns in relation to the main fish concentration areas. These have been selected, from surveys made between 1959 and 1963, to cover the principal months of the fishing season and to show the extreme ranges, and both simple and complex patterns, of temperature and salinity. Generally speaking, the main fish concentrations have built up and maintained themselves within the main deeper-water channel, regardless of absolute values of temperature and salinity or of changes in them. In February 1963 most of the fish were in water ranging between 0 and 0.5 °C, some even being in sub-zero temperatures (down to —0.2 °C), but these fish were still quite lively when caught and not unduly affected by these exceptional temperatures.

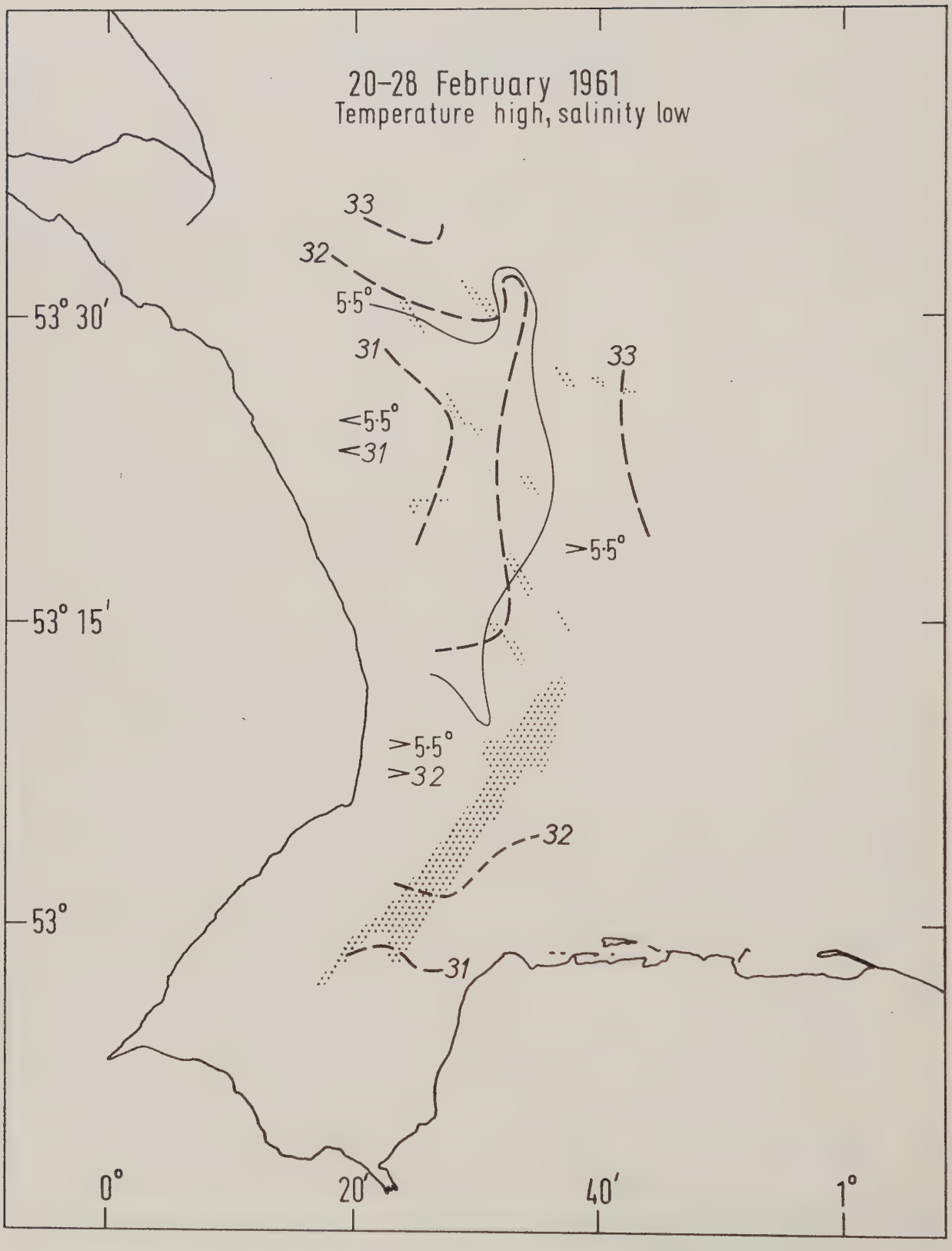
In some subsequent seasons (notably 1963–64, 1967–68 and to a lesser extent in 1964–65) changes in the distribution of fishing effort indicated a marked shift in the main locus early in January from the Inner Wash to the Inner Dowsing and Lincolnshire coast grounds. The commercial boats reported that little was recorded on their sounders within the Inner Wash from early January onwards, and it seems that a genuine shift in the bulk of the fish did take place about this time. Hydrographic evidence from the Lynn Well lightvessel (Table 4) should be sufficient to show whether or not any unusual change in the hydrographic regime might be associated with these fish movements early in January. This table shows that the only consistent feature of the seasons in which there was a pronounced movement of fish towards the end of December and in early January (1963–64, 1964–65 and 1967–68) was a slight rise in salinity towards

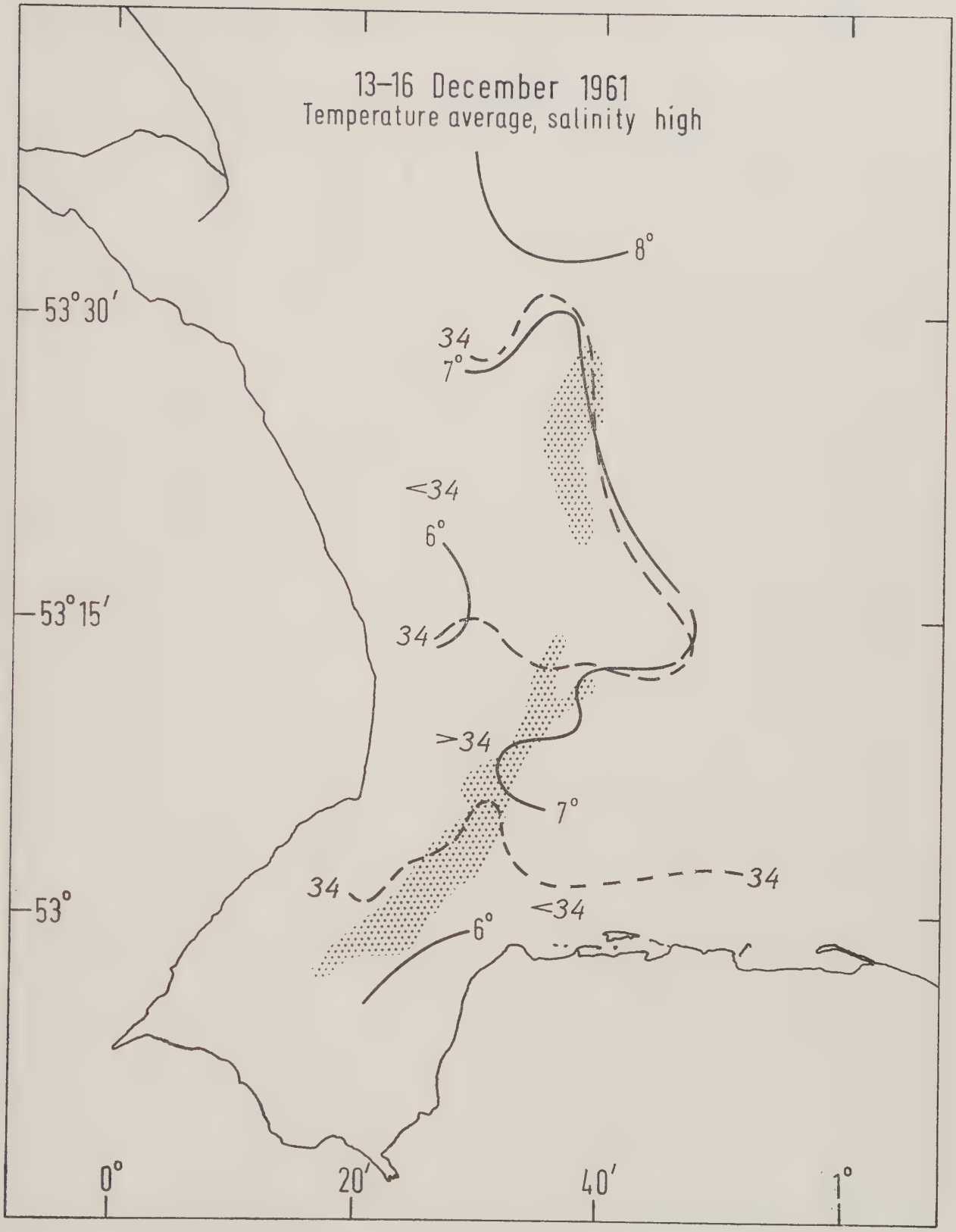
the end of December, compared with a continuing reduction in the other seasons (1965–66, 1966–67). This very slender evidence is inconclusive, but it does provide a possible lead to follow in future seasons. However, it is remarkable that such a slight change should be responsible *per se* for the movement of fish at this time, especially considering the general tolerance shown by this species to wide changes in temperature and salinity on other occasions, unless it is indicative of some other factor in the environment to which the fish are particularly sensitive at this stage of their overwintering phase.

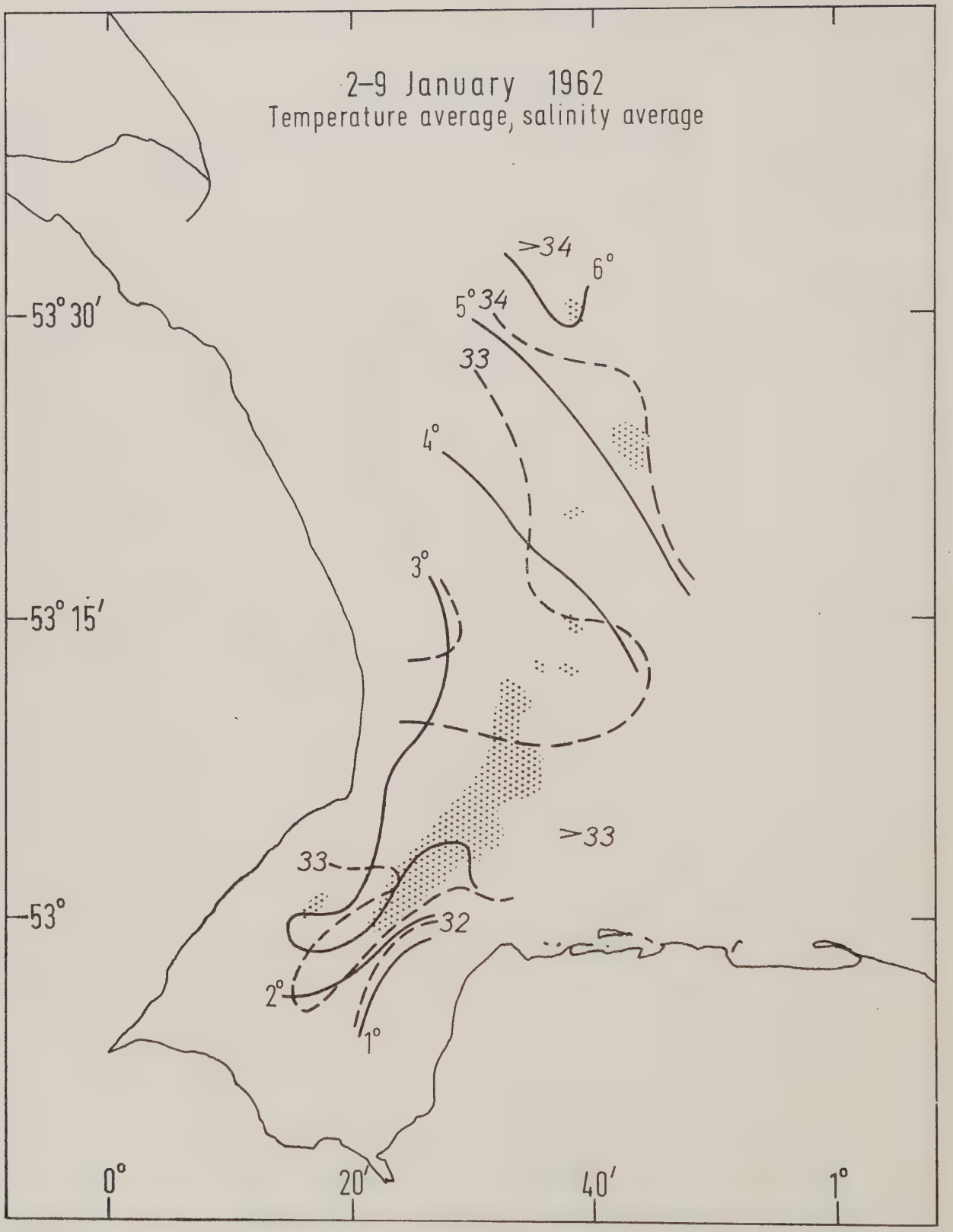
To sum up, it may be said that over the winter period these fish withdraw into relatively colder and less saline water (compared with offshore conditions), but temperature and salinity patterns seem to play no obvious role in determining the location of these overwintering concentrations within the estuary, and possibly some form of topographical orientation is involved. (The Thames Estuary sprats show a comparable type of aggregation each year, concentrations building up in certain channels each season, regardless of differences and changes in temperature or salinity.)



Figures 5–9 The main sprat concentration areas in relation to patterns of temperature (°C) and salinity (‰) for the seasons 1959 to 1963, showing the extreme ranges and both simple and complex patterns.


20–28 February 1961
Temperature high, salinity low
33
32
5·5°
31
<5·5°
<31
33
>5·5°
>5·5°
>32
32
31
53° 30′
53° 15′
53°
0°
20′
40′
1°


13–16 December 1961
Temperature average, salinity high
8°
53° 30′
34
7°
<34
6°
53° 15′
34
>34
7°
34
34
<34
53°
6°
0°
20′
40′
1°


2–9 January 1962
Temperature average, salinity average
>34
6°
5°34
33
4°
3°
>33
33
32
2°
1°
53° 30′
53° 15′
53°
0°
20′
40′
1°

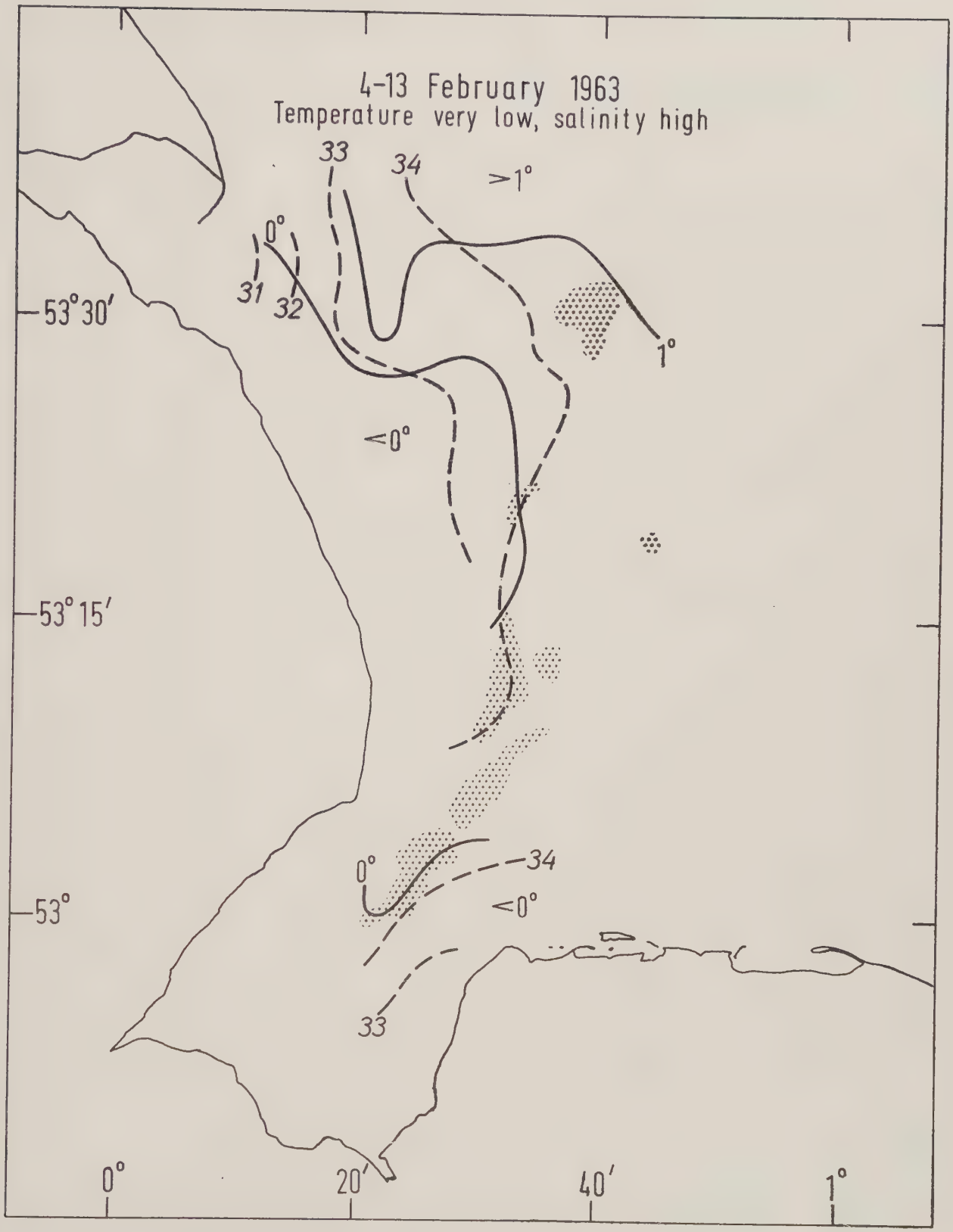

4-13 February 1963
Temperature very low, salinity high
33
34
>1°
0°
31
32
1°
53°30′
<0°
53°15′
0°
34
<0°
53°
33
0°
20′
40′
1°

Table 4 Temperature and salinity values at the Lynn Well lightvessel; mean weekly values, taken at high-water and low-water slack periods

Weeks ending	Temperature (°C)						Salinity (‰)					
	1963–64	1964–65	1965–66	1966–67	1967–68	Means	1963–64	1964–65	1965–66	1966–67	1967–68	Means
19 December	6.5	7.1	5.3	5.8	5.0	5.9	33.65	34.28	32.49	32.76	33.15	33.27
26 December	5.4	6.5	5.3	5.3	5.5	5.6	33.69	34.34	32.08	32.62	33.57	33.26
2 January	5.0	5.3	4.5	4.8	5.3	5.0	33.66	34.42	31.59	32.50	33.36	33.11
9 January	5.0	4.8	4.3	3.8	4.2	4.4	33.60	34.34	31.75	32.31	33.00	33.00
Means	5.5	5.9	4.9	4.9	5.0	5.2	33.65	34.34	31.98	32.55	33.27	33.16

Table 5 Seasonal assessments of the main areas fished, and the total catch from each (in tons)

Area	1958–59	1959–60	1960–61	1961–62	1962–63	1963–64	1964–65	1965–66	1966–67	1967–68
1 Inner Silver Pit					50			650		275
2 Inner Dowsing		260	85		345	595	1 250	2 440		1 220
3 Inner Wash	675	1 630	2 060	2 435	1 640	1 395	2 215	3 035	1 130	3 655
4 North Norfolk coast	515		35			515	155	5		
5 South Lincs. coast										2 950
6 North Lincs. coast						815	1 015	125		
7 Humber estuary						690				
8 Yorkshire coast						290				

TOPOGRAPHICAL DISTRIBUTION OF FISHING EFFORT

The information concerning fishing localities has been supplied in fairly precise detail on landing forms, particularly by the 40-foot pair-boats working on a daily basis, these usually making only two or three short hauls in much the same position on any one day. The Grimsby boats may fish over a wider area on each trip, but even so the fishing locality is generally restricted and can be fairly accurately assigned to one of these sub-areas.

Table 5 summarizes the seasonal changes in the areas fished and the catch from each, from 1958 to 1968. There are considerable differences over this period, particularly after the advent and increasing involvement of the Grimsby vessels. In the earlier seasons, when the smaller pair-boats predominated, fishing tended to be concentrated during November and December in the more extreme south-west end of the Wash, with a progressive shift seawards between January and March, until finally these boats were fishing at the limits of their useful daily working range. Monthly charts for the 1959–60 season (Figure 10) show the typical course of events outlined above. After the Grimsby boats began to participate on an increasing scale the localities fished became considerably extended, and more effort was expended in areas outside those previously worked by the smaller vessels. The 1963–64 season (Figure 11) shows this very well, with movement later in the season into the coastal area off Lincolnshire, the Humber Estuary and along the Yorkshire coast as far north as Bridlington Bay (off this chart). The 1965–66 and 1967–68 seasons also show that a greater proportion of the catch came from areas outside those worked in earlier seasons. A more detailed breakdown of catch and effort data by sub-areas and classes of vessel is given in Appendix Table A.

The positions of the main echo patches have been superimposed on some of the monthly distribution of fishing effort charts (Figures 10 and 11), where this information is available. These show a fair measure of agreement between the areas of main fishing effort and those of high echo density, bearing in mind that the distribution of fishing positions covers a whole monthly period, whereas the echo surveys show the position for a few days only within the month.

Although in some years the main fishing effort has remained wholly within the Inner Wash region throughout the season (e.g. 1961–62), most seasons have shown signs of a progressive shift seawards between January and March, the available echo survey evidence confirming that this represents a genuine shift in position of the main fish concentrations. In three seasons (1963–64, 1964–65 and 1967–68) a marked shift in fishing positions was evident by January, with movement into the Inner Dowsing and Lincolnshire coast areas, and in the 1963–64 season a steady progression northwards, until by March most of the sprat fishing was taking place along the Yorkshire coast between Spurn Head and Bridlington Bay (where a fishery developed in April). The change in fishing pattern may not show the complete picture of the stock's movements but probably shows the movement of at least part of it. Echo survey evidence towards the end of each season is unfortunately sparse, the best coverage being for November and December, less in January and February, and none in March. Towards the end of the 1963–64 and 1964–65 seasons, when sprat catches had dropped to a low level, the Lincolnshire coast fishery tended to persist due to a valuable by-catch of spring-spawning herring, some boats fishing almost entirely for these during the latter part of March and in early April.

The general pattern of events over this period has thus been an initial build-up of sprat concentrations during November, the fish then remaining fairly static until at least January, when either a fairly rapid shift in position takes place, or a more gradual change occurs, with the fish moving seawards along the main outlet channel of the Wash, or into the Lincolnshire coastal area.

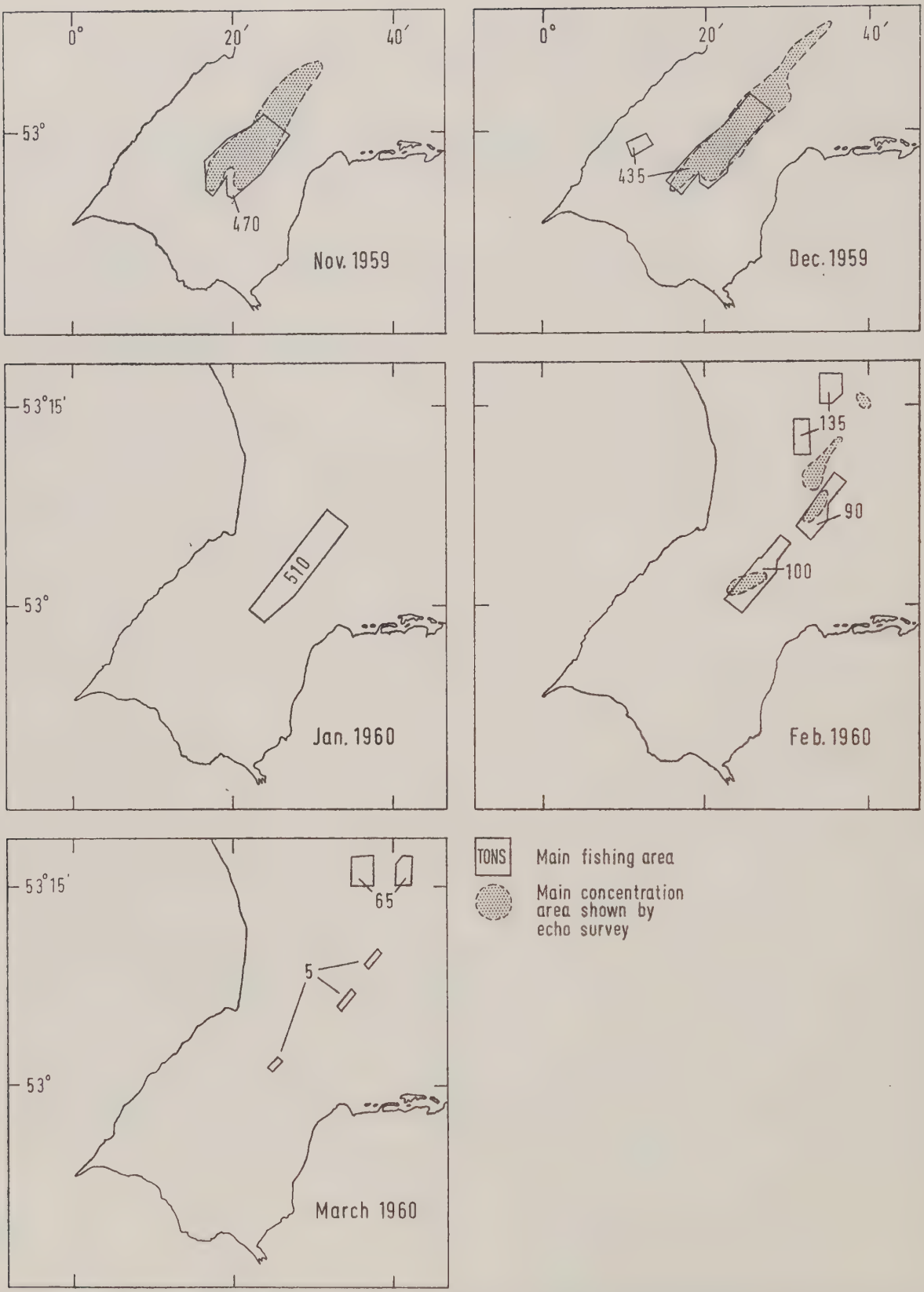


Figure 10 Monthly fishing charts for the 1959–60 season, when only the 40-foot pair-boats were operating.

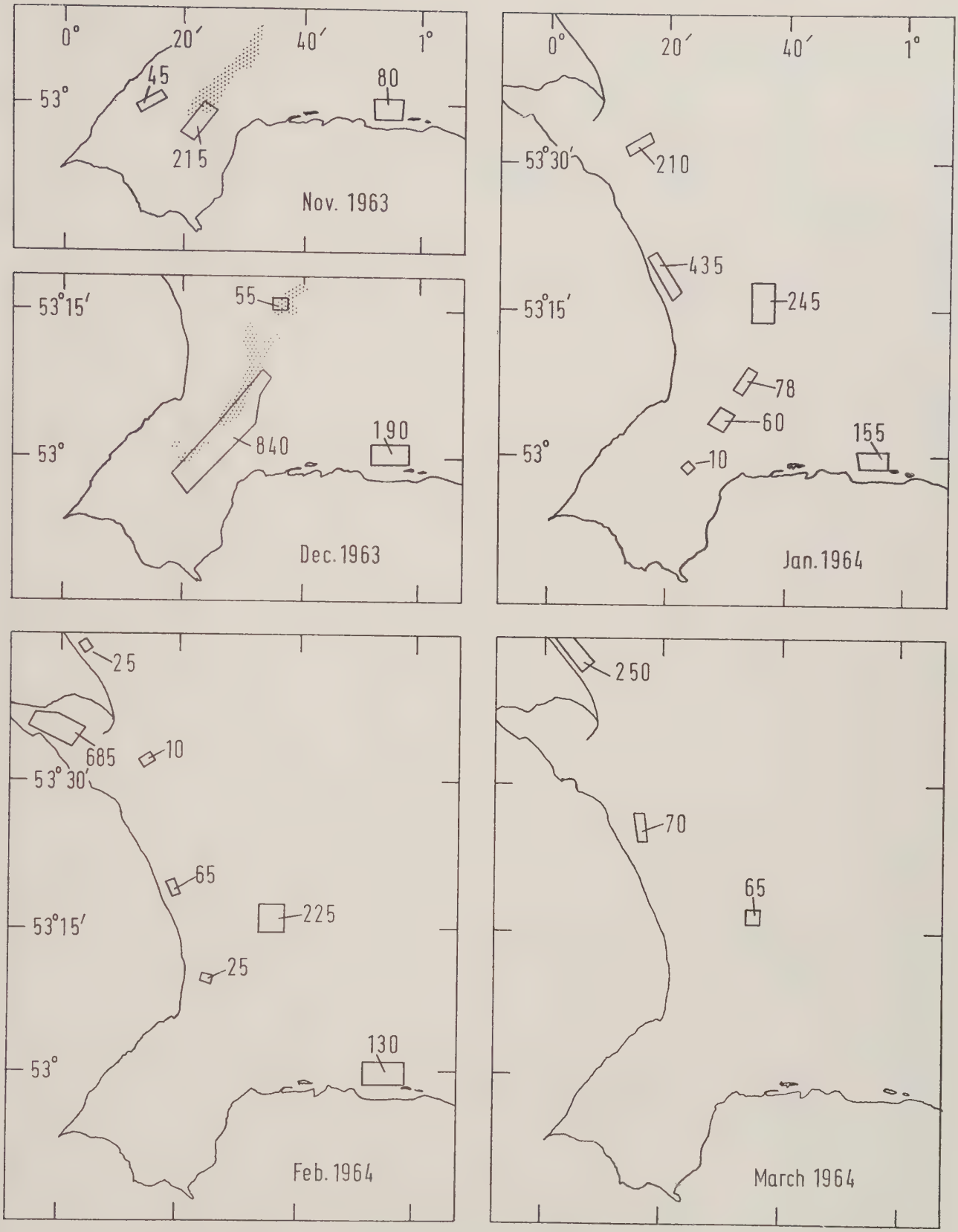


Figure 11 Monthly fishing charts for the 1963–64 season, showing the effect of the participation of Grimsby seiners in the fishery. (Key as in Figure 10).

Table 6 Timing and duration of the Wash sprat fishery, and the associated water temperatures and salinities from the Lynn Well lightvessel, derived from: 1959–63, research vessel observations made within a 5-mile sector of the lightvessel; 1964–67, monthly mean values of observations made from the lightvessel at 4-day intervals

Season	First peak week (week ending)	Final week (week ending)	Season's duration (weeks)	Temperature (°C)			Salinity (‰)		
				Nov.	Feb.	Difference	Nov.	Feb.	Difference
1959–60	14 Nov.	27 Mar.	20	9.4	4.9	—4.5	34.44	32.19	—2.25
1960–61	21 Nov.	6 Mar.	16	9.0	5.7	—3.3	32.47	32.29	—0.18
1961–62	21 Nov.	20 Mar.	18	8.5	–	–	34.00	–	–
1962–63	28 Nov.	27 Mar.	18	7.8	0.0	—7.8	33.55	34.22	+0.67
1963–64	28 Nov.	5 Mar.	15	8.4	4.0	—4.4	33.67	33.52	—0.15
1964–65	14 Nov.	20 Mar.	19	9.7	4.2	—5.5	34.33	33.90	—0.43
1965–66	28 Nov.	6 Mar.	15	8.7	4.3	—4.4	33.79	31.74	—2.05
1966–67	21 Nov.	13 Feb.	13	8.6	4.9	—3.7	32.92	32.91	—0.01
1967–68	28 Nov.	12 Mar.	16	8.9	4.0	—4.9	33.65	32.92	—0.73
Overall means				8.8	4.0	—4.8	33.65	32.96	—0.69

THE TIMING AND DURATION OF THE FISHERY IN RELATION TO ENVIRONMENTAL FACTORS

Table 6 shows on a seasonal basis the dates of the first peak weeks and the final weeks of the fishery, and the seasons' duration; the associated values of temperature and salinity in November and February and the changes in these during each season are also given.

Over the period 1958–1967 the fishery has usually commenced between the second and last weeks of November and terminated between the first and last weeks of March, showing a maximum difference in timing between seasons of up to three weeks. Seasons which start late do not necessarily end later, and vice versa, and the duration has varied between thirteen and twenty weeks, although the period of maximal catch-rates is usually much less than this. The two seasons which began earliest (1959–60 and 1964–65) showed rather higher November water temperatures and salinities than average, whilst those which began later tended to show lower temperatures.

Water temperatures have varied between 8.4 and 9.7°C near the beginning of each season and from 0.0 to 4.7°C towards the end, showing seasonal decreases ranging between 3.3 and 7.8°C. Salinities have varied between 32.47 and 34.44‰ early in the season, and from 31.74 to 34.22‰ near the finish, usually showing a reduction over the season, except in 1962–63 when freshwater run-off was severely restricted by prolonged low temperatures which froze the rivers and drainage areas.

The average annual temperature and salinity cycles recorded at the Lynn Well lightvessel between November 1963 and February 1968 are shown in Figure 12 to provide a general background against which the rates of change in temperature and/or salinity can be examined in relation to the timing of the fishery. The rate of heat loss is greatest between October and December, averaging about 3.5°C per month, salinity values also showing a decrease over this period. Warming-up is first noticeable between February and March after winter minimum temperatures in January/February; salinity, however, continues to decrease until April, but at a slower rate than previously.

Table 7 gives the differences in temperature and salinity between the months of October/November (covering the initial aggregation period of the fish) and January/February (beginning of dispersal), together with the timing of the fishery and the relative catch per unit effort in November and February of each season, expressed as a proportion of the maximum monthly average catch per effort recorded in that season. The information available for this analysis is limited to the period of continuous lightvessel observations from 1963 onwards, and any conclusions must be very tentative.

Over this period late-commencing seasons have predominated, and the timing showed no link with the rate of cooling or the change in salinity between October and November. Similarly the ending of a season did not relate to changes in temperature or salinity between January and February, but since the ending of a season determined from catch data may be due to one of a number of causes (e.g. weather, economic or fish availability factors), this date cannot be relied on to provide meaningful comparisons between seasons.

The relative catch per effort index for November can be the maximum in some seasons (1964–65, 1967–68), whilst in others it may be less than half that achieved later (1965–66, 1966–67); the latter two seasons do correspond with above-average cooling rates between October and November. The February catch per effort index was maximal in one season (1966–67), but was generally around 0.5 or less (the longer-term average for the period 1959–60 to 1967–68 was 0.60). The two seasons with the highest February catch per effort index (1963–64 and 1966–67) did correspond with above-average cooling between January and February, but so did the 1964–65 season which had a catch per effort index of only 0.49, although a much greater drop in salinity was also recorded in this season.

A successful sprat fishery is dependent on fish behavioural changes bringing about a high degree of concentration of fish within a relatively localized area, and the above analysis of timing indicates that a fairly precise mechanism is involved which is not readily upset by differences in the hydrographic regimes. Over the period of the fishery the sprats are relatively inactive, with no feeding taking place and little visible sign of gonad maturation until near the end of the season. Spawning and feeding both commence in the latter part of March, this marking the termination of fishing when the overwintering concentrations have thinned out to an uneconomically exploitable density. The 'build-up' phase early in the season can

Table 7 Seasonal analysis of differences in temperature and salinity, together with the timing of the fishery and the catch per effort index in November and February, i.e. the catch per effort in those months expressed as a proportion of the maximum monthly average catch per effort recorded in that season

Season	First peak week (week ending)	October/November difference		Nov. C.P.E. / Max. C.P.E.	Final week (week ending)	January/February difference		Feb. C.P.E. / Max. C.P.E.
		Temp. (°C)	Salinity (‰)			Temp. (°C)	Salinity (‰)	
1963–64	28 November	—2.1	—0.14	0.81	5 March	—0.5	—0.07	0.84
1964–65	14 November	—2.9	+0.04	1.00	20 March	—0.5	—0.40	0.49
1965–66	28 November	—4.4	+0.09	0.40	6 March	+0.7	0.00	0.56
1966–67	21 November	—4.7	—0.41	0.36	13 February	—0.8	+0.34	1.00
1967–68	28 November	—3.3	—0.31	1.00	12 March	+0.1	—0.08	0.27
Means		—3.7	—0.12	0.71		+0.1	—0.04	0.63

be very rapid, taking place over a matter of days in some years (shown by changes in catch per unit of effort in the early weeks and also by echo surveys), whilst the dispersal phase is generally much more gradual, taking place over a period of weeks.

This overwintering assembly of sprats may be basically construed as a pre-spawning aggregation, and the behavioural changes over this period may thus be linked with the maturation cycle. This will in turn be under hormonal control which is initiated by, and phased with, external environmental changes. There is evidence that light (i.e. daylength) and temperature may be the most important of these (Woodhead and Woodhead 1965).

Figure 13 shows the phasing of daylength and water temperature in the Wash area and their relation to the periods of aggregation and dispersal of sprats. Aggregation occurs after water temperatures have dropped well below their summer maximum but have not reached their minimum, and at decreasing daylengths following the autumnal equinox. This equinox might actually mark the beginning of a change in behaviour which produces a general movement into coastal waters; the commencement of the fishery in November may signify the final stages of this migration. The dispersal phase occurs when water temperatures are minimal near the time of the spring equinox, when daylengths are increasing. Daylength may thus be an important factor in governing the timing of the observed changes in behaviour pattern of sprats, especially since this is a constant environmental cycle which is virtually free from the more irregular fluctuations associated with other factors such as temperature or salinity. Figure 13 also gives general plankton production cycles for the western half of the southern North Sea (derived from Colebrook and Robinson 1965), in relation to the main spawning period of sprats in this region. The phytoplankton production cycle gives an indication of spring and autumn peaks, whereas the copepods show only a single well-defined peak falling between June and August. The main sprat spawning period (May–June) immediately precedes this peak, this timing ensuring that maximum numbers of developing larvae occur when their food supply is near its maximum. The maturation cycle is thus phased with the production cycle in such a way that both early sprat stages and post-spawning adults encounter optimum feeding conditions. Feeding usually ceases towards the end of October, when copepods are approaching their minimum level of abundance, but the degree to which a lower limiting density of food organisms is responsible, or whether internal physiological factors are also involved, is not known.

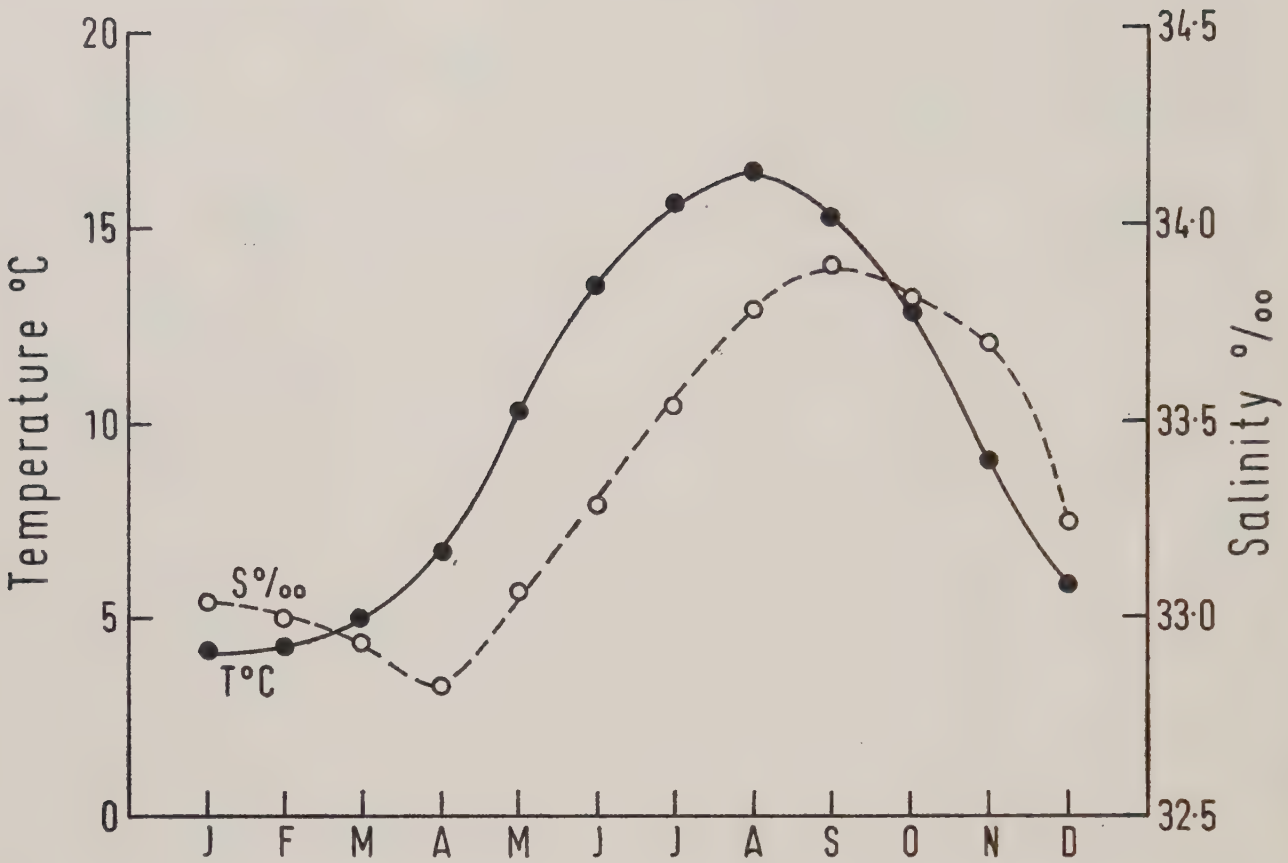


Figure 12 Average monthly mean temperature and salinity values at the Lynn Well lightvessel for the period November 1963 to February 1968.

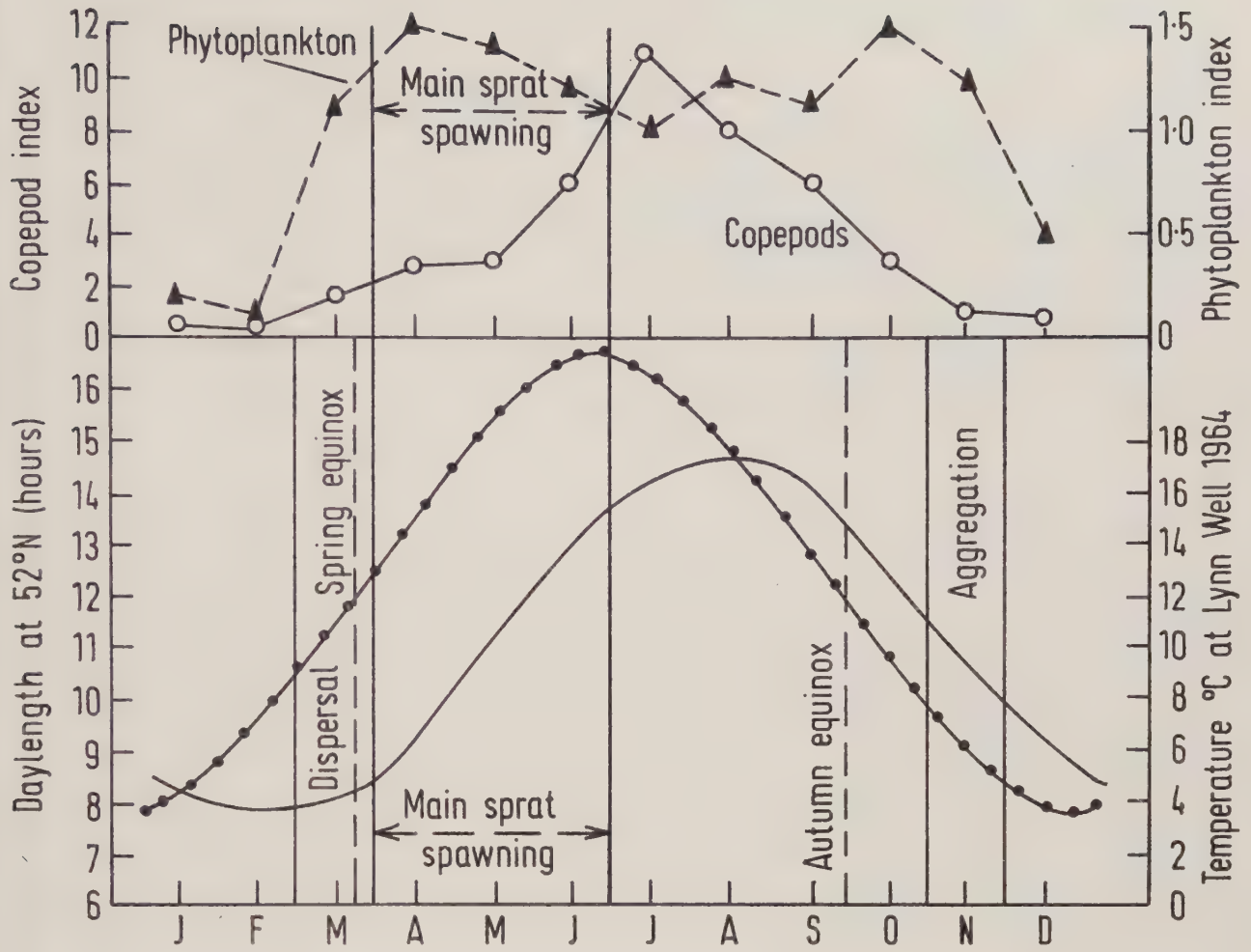


Figure 13 Plankton production cycles in Area D2, the western half of the southern North Sea (Colebrook and Robinson 1965), in relation to daylength, water temperature and the periods of aggregation and dispersal of sprats.

AGE DETERMINATION IN THE SPRAT

Sprat scales are very readily detached, and as this is a trawl fishery most fish from commercial samples are virtually scaleless, particularly along the flank where the scales most suitable for age determination are situated. Nevertheless, in the first season attempts were made to use scales for age determinations, but were not subsequently continued because of the disproportionate amount of time needed to find fish with scales worth removing and mounting. There was also found to be a good measure of agreement in a check series of age determinations made using both scales and otoliths. Otoliths have therefore been used throughout, and although they are very small they have been found to be quite easy to read, certainly up to five years old. The maximum age recorded with any certainty has been seven years, although fish of this age are very scarce. For practical purposes the upper age limit in the fishery may be taken as five years, but fish of this age contribute only a very small part of the total catch.

METHOD USED; GENERAL DESCRIPTION OF SACCULAR OTOLITHS

A selection of pairs of saccular otoliths from sprats of various ages are shown in Plates 5 and 6. These represent fish of between one and six years old taken during the 1960-61 Wash sprat fishery, the first-year examples being at a relatively greater magnification than the older ones. The lengths of these first-year fish ranged between 3.0 and 4.3 cm, the smallest still being in the immediate post-larval metamorphic stage. The main visual feature of the otolith structure at this size is a central nucleus region, which is usually fairly opaque, around which appears a zone laid down during the period of metamorphosis. This can either take the form of a discrete hyaline annulus or show as a more diffuse band of relatively less opaque material, and has been termed the metamorphic ring or zone. It has been a fairly constant feature of most of the otoliths examined and can sometimes remain distinct in older fish, although it often becomes less obvious due to a general thickening of the otolith over this central area. The first three opaque zones are usually well-defined, but subsequently become much narrower, until in older fish the outer zones become very thin and are often clearly visible only towards the tips of the long axis. These opaque zones are laid down during the summer months and thus equate with the growing period; otoliths taken from fish in August show opaque zones right to the edge, but towards the end of October a thin hyaline margin is already evident, and during the winter months, when feeding ceases, the hyaline edge is quite prominent. The age determinations have in fact been made in terms of the number of opaque or growth zones present, since the beginning of the fishery conveniently marks the end of a growing period. The general scheme adopted for age determination has been to assume that all fish caught between October and March inclusive have nearly completed or completed a growth zone, these fish being allocated an age based on the number of growth zones including the ultimate one, whilst any taken between April and September inclusive are given an age estimate based on the number of visible winter rings followed by a plus designation to indicate that they are entering or within a growth period following the last winter ring.

Table 8 Summary of numbers of sprats per landing (in thousands) by length groups and seasons, for 40 foot pair-boats

Length (cm)	1958–59	1959–60	1960–61	1961–62	1962–63	1963–64	1964–65	1965–66	1966–67	1967–68	Total	$\bar{N}$	%
3.5	–	–	–	–	–	–	–	0.8	0.6	–	1.4	0.14	0.01
4.0	–	–	–	0.1	–	6.8	6.4	1.3	2.3	2.4	19.3	1.93	0.22
4.5	–	0.1	–	0.1	–	13.2	21.9	2.6	7.5	18.0	63.4	6.34	0.72
5.0	2.2	0.8	0.2	0.1	–	14.5	16.7	3.4	8.1	28.2	74.2	7.42	0.84
5.5	4.1	1.2	0.7	0.4	–	11.2	17.9	3.5	1.1	35.9	76.0	7.60	0.87
6.0	32.0	3.0	5.5	1.4	–	14.5	17.9	1.9	2.8	44.4	123.4	12.34	1.41
6.5	92.1	5.1	7.0	5.7	1.3	21.9	23.1	1.6	21.3	90.4	269.5	26.95	3.07
7.0	93.9	8.9	9.9	20.3	5.6	20.6	27.3	5.8	25.2	132.4	349.9	34.99	3.99
7.5	81.8	19.2	9.2	33.9	28.5	13.8	43.0	65.2	90.8	195.2	580.6	58.06	6.62
8.0	43.9	94.4	13.5	60.1	113.6	13.3	129.1	129.9	160.4	285.1	1 043.3	104.33	11.89
8.5	24.1	117.4	27.2	84.7	71.1	31.1	150.2	119.4	97.2	359.0	1 081.4	108.14	12.33
9.0	30.0	105.2	64.7	134.0	64.4	44.3	110.3	126.8	87.4	298.4	1 065.5	106.55	12.14
9.5	46.0	69.9	94.0	107.1	55.2	65.2	83.9	119.2	131.7	109.0	881.2	88.12	10.04
10.0	92.0	57.8	115.6	84.1	59.3	60.0	83.2	89.6	120.7	47.3	809.6	80.96	9.23
10.5	101.8	38.6	96.9	50.0	48.9	59.3	72.6	74.3	70.7	53.2	666.3	66.63	7.59
11.0	65.9	27.8	75.7	47.0	50.7	52.0	58.8	51.7	33.9	42.5	506.0	50.60	5.77
11.5	39.9	16.0	39.3	33.3	33.5	42.0	44.2	42.8	19.6	33.0	343.6	34.36	3.92
12.0	25.9	10.0	29.3	29.0	30.8	38.0	30.4	31.4	19.0	17.9	261.7	26.17	2.98
12.5	12.0	8.1	12.1	15.9	17.1	42.8	31.6	16.8	14.9	17.9	189.2	18.92	2.16
13.0	4.0	7.7	8.8	12.2	11.7	40.7	28.4	12.5	14.3	15.7	156.0	15.60	1.78
13.5	2.4	5.6	7.2	5.6	5.2	28.3	24.2	9.3	7.5	9.0	104.3	10.43	1.19
14.0	2.0	5.6	5.6	2.2	2.6	11.5	16.7	4.7	6.9	4.2	62.0	6.20	0.71
14.5	1.6	3.4	4.0	0.7	0.8	3.6	8.5	2.4	4.0	1.1	30.1	3.01	0.34
15.0	1.2	1.7	2.8	0.3	0.8	0.6	1.2	1.5	1.1	1.1	12.3	1.23	0.14
15.5	0.8	0.4	1.2	0.1	0.4	0.1	–	0.2	–	–	3.2	0.32	0.04
16.0	–	0.1	0.2	–	–	–	–	0.1	–	–	0.4	0.04	0.00
16.5	–	–	0.1	–	–	–	–	–	–	–	0.1	0.01	0.00
Total	799.6	608.0	630.7	728.3	601.5	649.3	1 047.5	918.7	949.0	1 841.3	8 773.9	877.39	100.00
Total number measured	8 023	12 707	15 276	12 912	7 772	8 307	7 572	7 575	1 651	3 074			
Predominant age-groups	1, 3	2	3	2	2	3	2	2	3	1			

Table 9 Age-group analysis of the landings in the Wash sprat fishery (1958–1968)

Season	Age							Totals
	1	2	3	4	5	6	7	
	Percentage distribution by weight							
1958–59	16.53	26.49	49.12	6.87	0.98	–	–	99.99
59–60	1.94	64.20	18.62	14.60	0.55	0.09	–	100.00
60–61	1.83	24.74	59.99	5.95	6.58	0.90	0.01	100.00
61–62	5.73	50.33	16.44	25.85	0.72	0.74	0.20	100.01
62–63	0.12	57.59	23.86	11.15	7.16	0.12	–	100.00
63–64	1.84	12.25	75.80	8.69	1.17	0.25	–	100.00
64–65	3.53	33.81	37.35	24.57	0.74	–	–	100.00
65–66	0.17	75.42	19.15	3.84	1.20	0.22	–	100.00
66–67	2.99	25.12	66.93	2.91	1.38	0.66	–	99.99
67–68	49.31	39.39	8.21	2.47	0.31	0.17	0.14	100.00
Means	10.68	40.31	36.52	10.25	1.89	0.34	–	
	Percentage distribution by number							
1958–59	44.63	22.63	29.60	2.82	0.32	–	–	100.00
59–60	5.38	77.06	11.79	5.63	0.13	0.01	–	100.00
60–61	6.30	30.12	55.74	3.92	3.40	0.52	–	100.00
61–62	12.46	56.79	11.66	18.15	0.38	0.44	0.12	100.00
62–63	0.39	66.80	18.64	9.73	4.37	0.06	–	99.99
63–64	14.30	18.71	59.31	6.62	0.88	0.18	–	100.00
64–65	15.51	47.02	25.12	12.01	0.34	–	–	100.00
65–66	1.53	84.57	11.49	1.62	0.70	0.09	–	100.00
66–67	9.08	38.95	49.85	1.27	0.67	0.18	–	100.00
67–68	69.10	27.00	3.09	0.65	0.06	0.06	0.03	99.99
Means	24.53	44.57	24.39	5.48	0.88	0.14	0.01	
	Tons per landing							
1958–59	0.79	1.27	2.35	0.33	0.05	–	–	4.79
59–60	0.07	2.51	0.73	0.57	0.02	<0.01	–	3.90
60–61	0.10	1.31	3.18	0.32	0.35	0.05	<0.01	5.31
61–62	0.29	2.53	0.83	1.30	0.04	0.04	0.01	5.04
62–63	<0.01	2.50	1.04	0.48	0.31	<0.01	–	4.34
63–64	0.11	0.71	4.39	0.50	0.07	0.01	–	5.79
64–65	0.26	2.48	2.74	1.80	0.05	–	–	7.33
65–66	0.01	5.13	1.30	0.26	0.08	0.01	–	6.79
66–67	0.17	1.46	3.90	0.17	0.08	0.04	–	5.82
67–68	4.39	3.50	0.73	0.22	0.03	0.01	0.01	8.89
Means	0.62	2.34	2.12	0.59	0.11	0.02	<0.01	5.80

Table 9 (continued)

Season	Age							Totals
	1	2	3	4	5	6	7	
	Numbers per landing (thousands)							
1958–59	356.8	180.9	236.6	22.5	2.6	–	–	799.4
59–60	32.7	468.8	71.7	34.2	0.8	0.1	–	608.3
60–61	39.7	190.0	351.7	24.7	21.4	3.3	–	630.8
61–62	90.8	413.7	84.9	132.2	2.7	3.2	0.9	728.4
62–63	2.3	401.8	112.1	58.6	26.3	0.4	–	601.5
63–64	92.9	121.5	385.2	43.0	5.7	1.2	–	649.5
64–65	162.4	492.6	263.1	125.9	3.5	–	–	1 047.5
65–66	14.1	779.1	105.9	14.9	6.4	0.8	–	921.2
66–67	88.9	366.4	472.6	12.6	6.6	1.9	–	949.0
67–68	1 272.7	497.3	56.9	12.0	1.1	1.1	0.6	1 841.7
Means	215.3	391.2	214.1	48.1	7.7	1.2	0.1	877.7
	Tons per hour's fishing							
1958–59	(0.58)*	(0.93)*	(1.72)*	(0.24)*	(0.03)*	–	–	(3.50)*
59–60	0.04	1.28	0.37	0.29	0.01	<0.01	–	2.00
60–61	0.06	0.87	2.10	0.21	0.21	0.03	–	3.48
61–62	0.12	1.04	0.34	0.54	0.01	0.01	<0.01	2.07
62–63	<0.01	1.06	0.44	0.21	0.13	<0.01	–	1.85
63–64	0.06	0.43	2.69	0.31	0.04	0.01	–	3.54
64–65	0.09	0.85	0.93	0.61	0.02	–	–	2.50
65–66	<0.01	2.30	0.58	0.12	0.04	0.01	–	3.05
66–67	0.12	1.04	2.78	0.12	0.06	0.03	–	4.15
67–68	2.76	2.21	0.46	0.14	0.02	0.01	<0.01	5.60
Means	0.38	1.20	1.24	0.28	0.05	0.01	<0.01	3.16
	Number per hour's fishing (thousands)							
1958–59	(260.5)*	(132.1)*	(172.8)*	(16.4)*	(1.9)*	–	–	(583.7)*
59–60	16.7	239.6	36.6	17.5	0.4	0.1	–	310.9
60–61	26.2	125.2	231.8	16.3	14.1	2.2	–	415.8
61–62	37.4	170.4	35.0	54.5	1.1	1.3	0.4	300.1
62–63	1.0	171.2	47.8	24.9	11.2	0.2	–	256.3
63–64	56.8	74.4	235.7	26.3	3.5	0.7	–	397.4
64–65	55.5	168.3	89.9	43.0	1.2	–	–	357.9
65–66	6.3	349.5	47.5	6.7	2.9	0.4	–	413.3
66–67	61.4	263.2	336.8	8.6	4.5	1.2	–	675.7
67–68	800.8	312.9	35.8	7.5	0.7	0.7	0.4	1 158.8
Means	132.3	200.7	127.0	22.2	4.2	0.7	0.1	487.2

* Estimated values

Table 10 Year-class strength analysis: (a) data summed for fish of all ages over the period of their productive life in the fishery; (b) data for two- and three-year-old fish only

Year-class	(a) Fish of all ages				(b) Two- and three-year-old fish							
	Age range (years)	Contribution to the catch			Age range (years)	Contribution to the catch			Mean catch per unit effort (unweighted)		Percentage contribution to the catch	
		Weight (tons)	Numbers ($\times 10^{-6}$)	Effort (hours)		Weight (tons)	Numbers ($\times 10^{-6}$)	Effort (hours)	Weight (tons/hour)	Numbers (thousands/hour)	Weight	Numbers
1957	2–5	814.5	91.0	2 137	2–3	667.0	79.5	1 338	0.63	90.5	21.7	16.1
1958	2–5	3 297.5	447.2	3 860	2–3	2 522.5	370.9	1 589	1.70	236.6	61.9	67.1
1959	2–5	1 216.8	150.7	4 107	2–3	940.8	119.2	1 799	0.64	94.1	20.4	19.5
1960	2–5	2 117.6	287.0	5 317	2–3	1 709.5	252.7	2 271	0.87	145.0	38.3	39.9
1961	2–5	5 643.8	559.2	6 213	2–3	4 425.4	473.4	2 308	2.26	210.2	70.0	62.1
1962	2–5	2 520.7	272.2	5 392	2–3	2 264.7	257.2	3 046	0.82	84.5	25.3	22.4
1963	2–5	2 829.9	413.5	6 131	2–3	2 771.9	410.1	3 905	0.73	139.6	25.4	27.1
1964	2–4	5 678.7	820.0	4 298	2–3	5 478.6	809.1	2 346	2.36	348.1	74.0	78.4
1965	2–3	949.7	123.6	2 226	2–3	949.7	123.6	2 226	0.63	167.9	10.3	6.6
1966	2	3 191.7	452.7	1 952	2	3 191.7	452.7	1 952	2.20	312.9	39.4	27.0
1967	1	4 899.5	1 158.8	1 952	1	4 899.5	1 158.8	1 952	2.76	800.8	49.3	69.1

ANALYSIS OF THE CATCH

LENGTH DISTRIBUTIONS OF SAMPLES

Sprat measurements here refer to total length (i.e. to the tip of the longest caudal fin-rays) grouped by half-centimetre units; thus the 8 cm group contains all fish between lengths of 8.00 and 8.49 cm. Table 8 shows the length distributions of all the samples taken from the commercial fishery in each season from 1958 to 1967, in terms of the mean numbers per landing of each half-centimetre group. To maintain continuity between seasons the catch per landing index used as a raising factor has been that of the 40-foot pair-boat units alone, these having been involved in the fishery over the whole period.

The differences in length distributions between seasons are due mainly to the fact that in any particular season a single year-class has generally predominated, and when it has been a particularly strong one (e.g. the 1958) its presence can produce a gradual shift in modal length in successive seasons. This shows very clearly over the first three seasons, where the 1958 year-class shows first a well-defined peak in the 7.0 cm group, next in the following season at 8.5 cm, and then in its third year at 10.0 cm.

The mean length distribution for the whole period shows a single prominent mode at 8.5 cm, with nearly half the total number falling within the 8.0–9.5 cm length groups. The preferred length range for canning purposes is about 9.0–11.0 cm, whilst processes such as smoking or marinating require fish above 12.0 cm; the prospective long-term yields for these two outlets are thus about 45 per cent and 10 per cent of the season's catch respectively. This has been the main reason why in most seasons the majority of the catch has been used either for petfoods or meal and oil reduction.

AGE-GROUP CONTRIBUTIONS BY WEIGHT AND NUMBERS

A breakdown of age-group contributions in each season, expressed as percentage weight distributions, catches per landing and catches per hour's fishing by weight and numbers, is given in Table 9. It is evident that in most seasons two- and three-year-old fish have between them constituted by far the major part of the catch; the following summary table shows this more clearly:

Season	Percentage contribution of two- and three-year-old fish to the total catch	
	Weight	Numbers
1958–59	75.6	52.2
1959–60	82.8	88.9
1960–61	84.7	85.9
1961–62	66.8	68.5
1962–63	81.5	85.4
1963–64	88.1	89.4
1964–65	71.2	72.1
1965–66	94.6	96.1
1966–67	92.0	88.8
1967–68	47.6	30.1
Means	78.5	75.7

Fish beyond the age of four years have not made any significant contribution to the catch, and only strong broods such as those of 1958 and 1961 have appeared in any quantity at four years old. Some year-classes have made their major contribution at two years, others when three years old, but overall, as the average distribution shows, there has not been a great deal of difference between weight yields when two and three years old. First-year fish rarely contribute a large amount by weight, the main exception being the 1967–68 season.

Entry of the larger broods has been heralded by the appearance in quantity of large first-year fish in the catch (1958–59, 1961–62, 1964–65 and possibly 1967–68), the important component being the numbers caught above about 7.0 cm in length (this being near the 50 per cent selection point for the size of mesh used). The 1963–64 season also yielded large numbers of first-year fish, but these were mainly small and below the mesh selection size. They were caught more or less incidentally, due to a shift in the main fishing area closer inshore than usual during that season, the boats thus intruding into an area where the smaller first-year fish usually predominate. Catch-rates were high and these small fish were retained due to the meshes becoming masked by larger fish. The 1967–68 season recorded an exceptional abundance of large first-year fish and it will be of great interest to see how the future yield of this brood will compare with previous outstanding broods. On the other hand, however, the 1962 year-class was very weakly represented in its first year (1962–63 season) but progressively increased its representation at two and three years of age, thus showing an increase in availability as it became older. (This brood showed the same trend in the Thames sprat fishery on a much larger scale).

Table 11 Year-class rankings at two and three years of age

Year-class	Total weight	Total number	Catch per unit effort		Percentage contribution to the catch when two and three years old	
			Weight	Numbers	Weight	Numbers
1964	1	1	1	1	1	1
1961	2	2	2	3	2	3
1958	4	4	3	2	3	2
1963	3	3	6	6	5	5
1960	6	6	4	5	4	4
1962	5	5	5	9	6	6
1965	7	7	8	4	9	9
1959	8	8	7	7	8	7
1957	9	9	9	8	7	8

ANALYSIS OF RELATIVE YEAR-CLASS STRENGTHS

Table 10 shows the total contributions to the catch of each year-class by weight and numbers, summed over the period of useful productive life in the fishery (two to five years inclusive where possible), and similarly for two- and three-year-olds only, the ages at which they normally contribute most to the catch. Mean values of the catch-rate expressed in weight and numbers caught per hour's fishing when two and three years old are also given for each brood, together with their percentage contribution to the total catch in the seasons during which they were exploited at these ages. In terms of total yield by year-classes over the ages two to five inclusive there is a difference of nearly seven times by weight and six times by number between the largest and the smallest (1961 and 1957), and even more in the case of the 1964 year-class at two to four years of age. However, this difference is probably somewhat exaggerated, since the 1957 brood encountered only about one-third of the fishing effort experienced by the later broods. When the yields at two and three years of age only are compared the orders of difference between the largest and smallest broods are still much the same, but in terms of catch per hour they reduce to a difference of about four times by weight and numbers. The relative contributions of each year-class to the total catch in the two seasons in which each was exploited at two and three years of age show differences of three-and-a-half to four times between the largest and smallest broods, both by weight and by numbers.

Within the scope of this analysis the relative contributions at two and three years of age probably provide the best estimates for ranking year-class strengths, and Table 11 summarizes these for each of the indices of abundance used, the year-classes being ranked in order of decreasing strength, with one as the maximum.

There is a good measure of agreement in ranking between the various measures of abundance used, although there are a few exceptions. These differences are mainly due to total weight and number being sensitive to changes in the level of fishing effort, whilst catch per unit effort can be influenced by changes in availability or the relative predominance of two- or three-year-old fish during the exploitation of a year-class. The 1963 year-class shows a lower ranking in terms of catch per unit effort than total catch, due to a large increase in fishing effort in the seasons (1964–65 and 1965–66) when this brood was two and three years old. On the other hand the 1962 brood showed a considerable difference in ranking within the catch per unit effort columns between weight (5) and number (9). This was due to increased availability at the age of three years, which raised the average weight but reduced the numbers.

AGE/LENGTH DISTRIBUTIONS

A detailed breakdown of length distributions by age-groups for each year-class (expressed as numbers per landing in each half-centimetre group recorded by 40-foot pair-boats) is given in Appendix Table B.

The mean lengths and standard deviations of different year-classes at each age are summarized in Table 12, together with the overall mean lengths at each age for the period 1958–1967. The overall mean length distributions for each age-group over this period are shown in Figure 14 as histograms. The first obvious point is the very wide overlap of length distributions between different age-groups. This could be basically due to the extended spawning period of the sprat (4–5 months in this region) generating a wide initial time base for the commencement of growth, and also to the presence of two groups of fish, particularly within the larger broods, showing different growth characteristics (fundamentally 'fast' and 'slow' growers). It has been postulated (Iles and Johnson 1962) that the slow-growing component can originate from fish spawned later in the year, which pass through their first winter as larval or immediate post-larval stages when too small to record an identifiable winter ring on their otoliths. When subsequently aged as adults they will thus be allocated to the year following that in which they were spawned. This same state of affairs has long been recognized in autumn-spawned herring. The presence of these two groups has been particularly evident within the largest year-classes (e.g. 1958, 1961 and 1964) and can produce a bimodality of length distribution for a given age, this tending to become more noticeable as the brood grows older. This is shown for the 1961 year-class over the ages one to four in Figure 15. The length distribution of first-year

Table 12 Mean lengths (cm), standard deviation (cm) and numbers of fish aged, by year-classes and age-groups

Year-class	Age-groups (years)														
	1			2			3			4			5		
	Mean	S.D.	Number	Mean	S.D.	Number	Mean	S.D.	Number	Mean	S.D.	Number	Mean	S.D.	Number
1954													13.1	1.89	8
1955										12.4	1.16	49	14.7	0.67	11
1956							11.1	0.85	259	12.8	1.36	220	12.6	1.76	250
1957				10.0	0.81	109	11.1	0.82	178	11.7	1.59	173	11.8	1.96	9
1958	7.3	0.65	93	9.2	0.85	351	10.7	1.10	1 043	11.0	1.21	48	11.6	1.10	66
1959	7.3	0.78	15	10.0	0.94	461	10.8	1.61	40	10.3	1.47	128	11.6	1.59	6
1960	7.4	0.64	210	9.6	1.01	323	10.6	1.68	282	11.4	1.70	57	12.7	–	3
1961	8.0	0.78	339	9.5	1.39	736	11.4	1.55	535	12.2	1.56	51	11.4	1.83	9
1962	7.3	0.48	8	9.4	1.26	262	11.1	1.38	133	12.5	1.88	39	11.6	–	3
1963	5.9	0.94	54	9.1	0.90	143	11.3	1.46	147	11.9	–	3	14.2	–	2
1964	6.4	1.18	28	9.5	1.26	495	10.4	0.79	100	13.0	1.43	16			
1965	5.3	0.75	13	8.5	0.80	60	11.6	1.58	54						
1966	6.8	1.07	30	9.8	1.23	192									
1967	8.0	1.11	142												
Overall means (1958–67)															
Weighted	7.6	1.21	–	9.4	1.17	–	10.9	1.33	–	11.6	1.64	–	12.0	1.57	–
Unweighted	7.0	0.84	–	9.5	1.04	–	11.0	1.28	–	11.9	1.34	–	12.5	1.54	–
Maximum ranges (cm)	3.0–9.5			6.5–13.5			7.0–15.0			8.0–15.5			9.5–16.5		

Plates 1 and 2 Two of the small pair-boats used for sprat fishing in the Thames Estuary and the Wash.

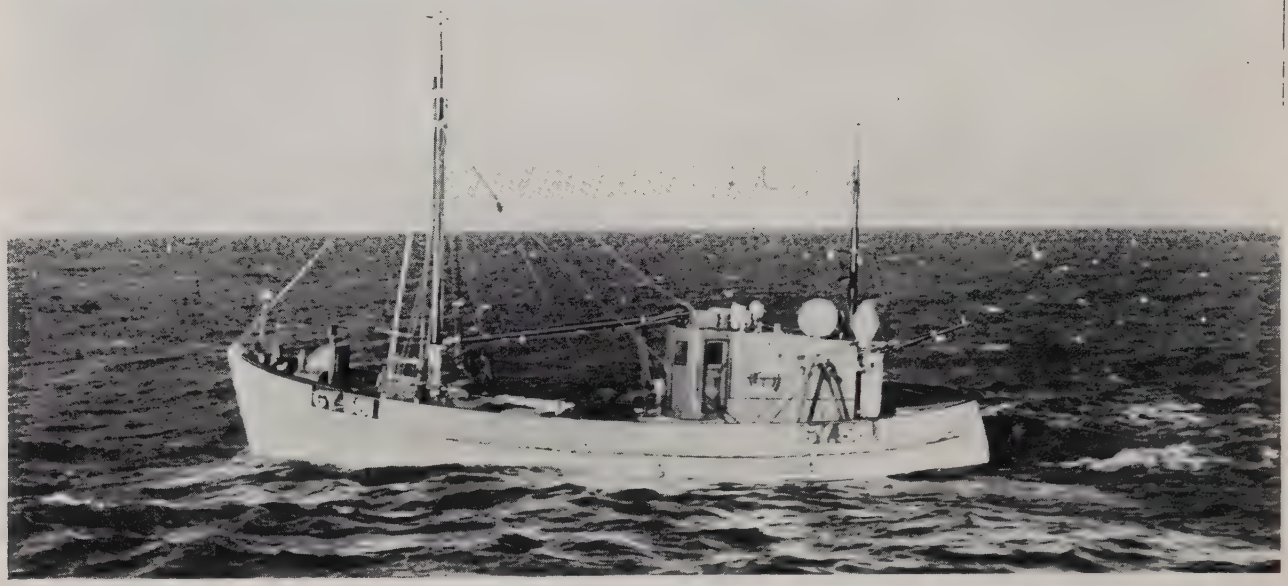


Plate 3 One of the larger seiner-type Grimsby vessels which have participated in the Wash sprat fishery since 1962.

Plate 4 Unloading sprats at a fish-meal plant.

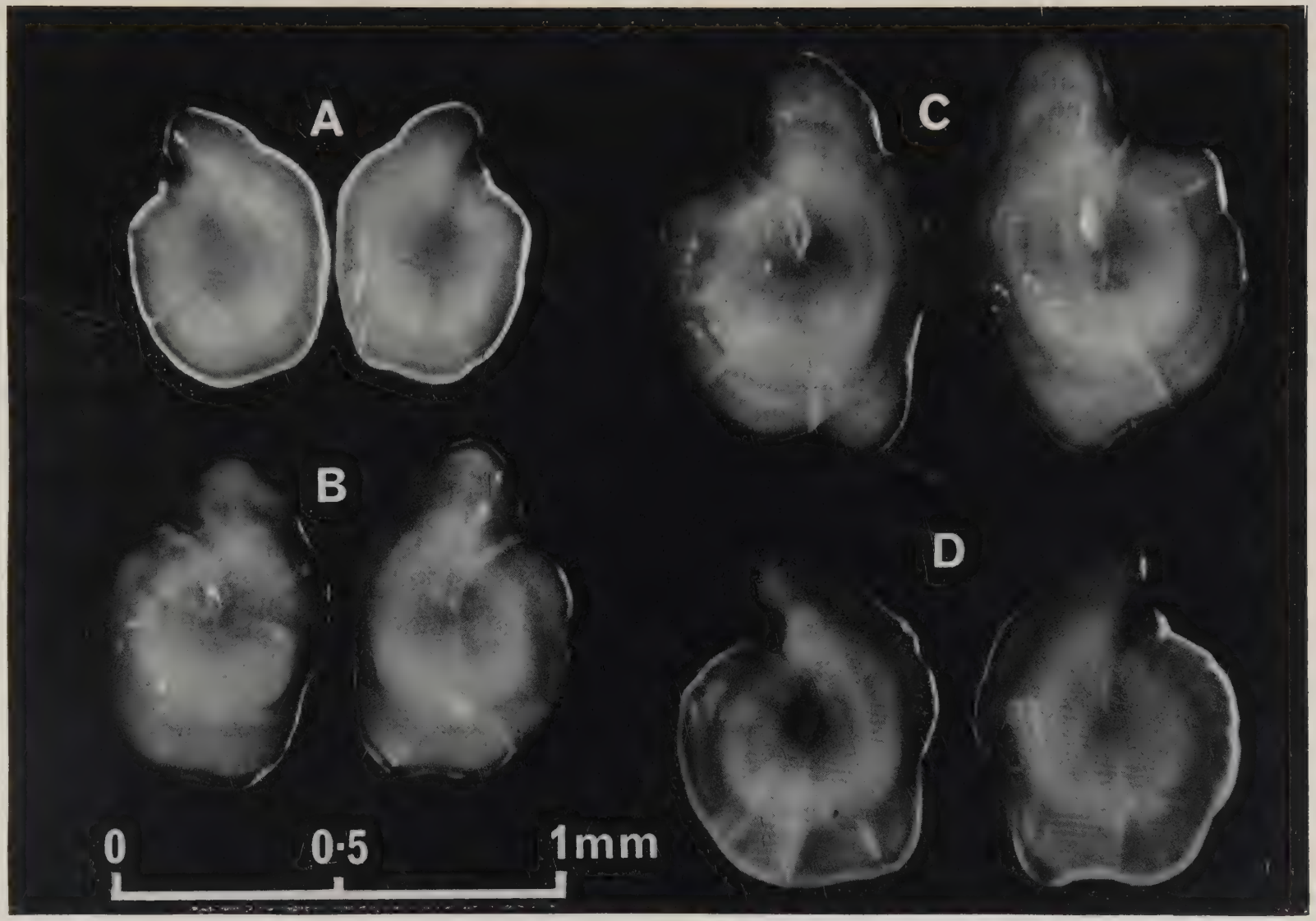


Plate 5 Examples of first-year sprat otoliths showing the development of the metamorphic zone in summer-caught fish;
A and B: from fish measuring 3.0 cm and 3.8 cm.
C and D: from fish measuring 4.3 cm and 3.9 cm.

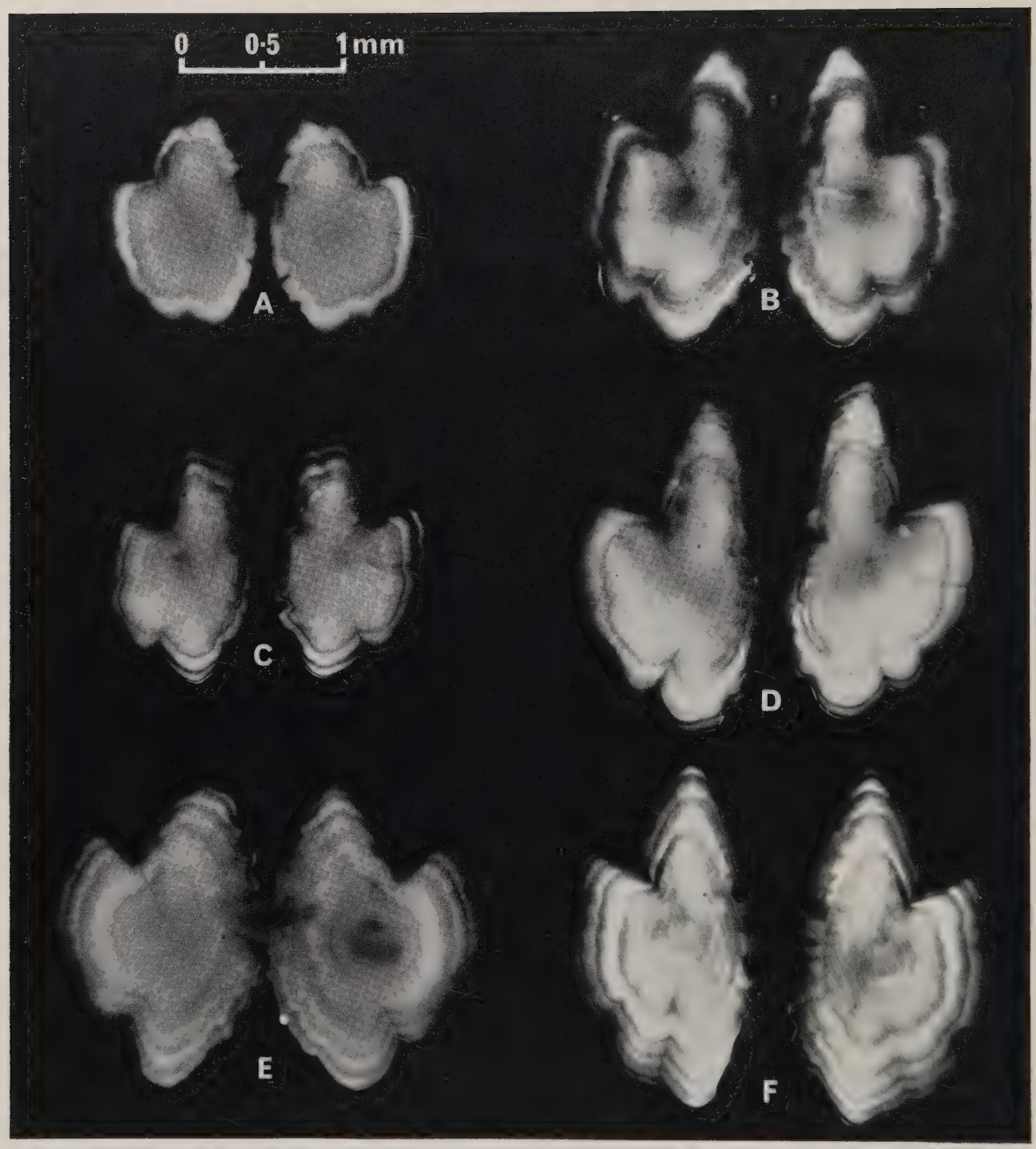


Plate 6 A selection of older sprat otoliths, showing the variation in otolith formation with size of fish, both within and between age-groups;
A and B: from two-year-old fish, measuring 8.0 cm and 13.0 cm.
C and D: from three-year-old fish, measuring 8.0 cm and 15.0 cm.
E: from a five-year-old fish, 15.0 cm in length.
F: from a six-year-old fish, 13.0 cm in length.

fish is very incomplete due to mesh selection (the 50 per cent level of retention being in the 6.5 cm length group), and also possibly because of the fact that until more recent seasons fishing has taken place only on the fringe of the main areas of whitebait distribution in the shallower inshore water (less than 5 fathoms depth).

The low mean length (5.9 cm) recorded for the 1963 year-class at one year of age is due to the fact that in the 1963–64 season a good proportion of the catch was taken close inshore (off the Lincolnshire coast) and from the River Humber, thus increasing the quantity of smaller whitebait present in the landings.

AN ASSESSMENT OF THE VULNERABILITY OF FIRST-YEAR FISH TO CAPTURE, ON THE BASIS OF LENGTH

The following method provides an approximate means of assessing the relative vulnerability of first-year fish to capture in the fishery. It involves comparing the actual length distribution of first-year fish (l_1) in the catch with the back-calculated length distributions made from otolith first-winter ring measurements on the same year-class when two and three years old. An example is given for the 1958 year-class in Figure 16, which shows the percentage length distributions of the one-year-old fish, obtained by both methods. It is clear that the fishery takes only the upper tail-end of the length distribution for one-year-old fish and, by rough calculation from the differences between the two distributions, about 16.7 per cent of this year-class was potentially vulnerable to capture on a size basis.

Table 13 Calculation of the mesh selection curve data for the 1958 year-class

Length group (cm)	l_1 distribution (‰)	% retention	Residual numbers (‰)	Calculated ratios between successive length groups	Catch ratios
3.0	47.5	–	–	–	–
3.5	100.5	–	–	–	–
4.0	84.7	–	–	–	–
4.5	96.4	–	–	–	–
5.0	123.2	0.08	0.99	1.76	1.87
5.5	119.8	1.46	1.75	7.89	7.88
6.0	150.0	9.20	13.80	2.88	2.87
6.5	147.3	27.00	39.80	1.02	1.02
7.0	53.7	75.00	40.30	0.87	0.87
7.5	39.9	87.50	34.90	0.49	0.49
8.0	18.6	93.00	17.30	0.94	0.24
8.5	16.5	98.00	16.20	0.13	–
9.0	2.1	100.00	2.10	–	–

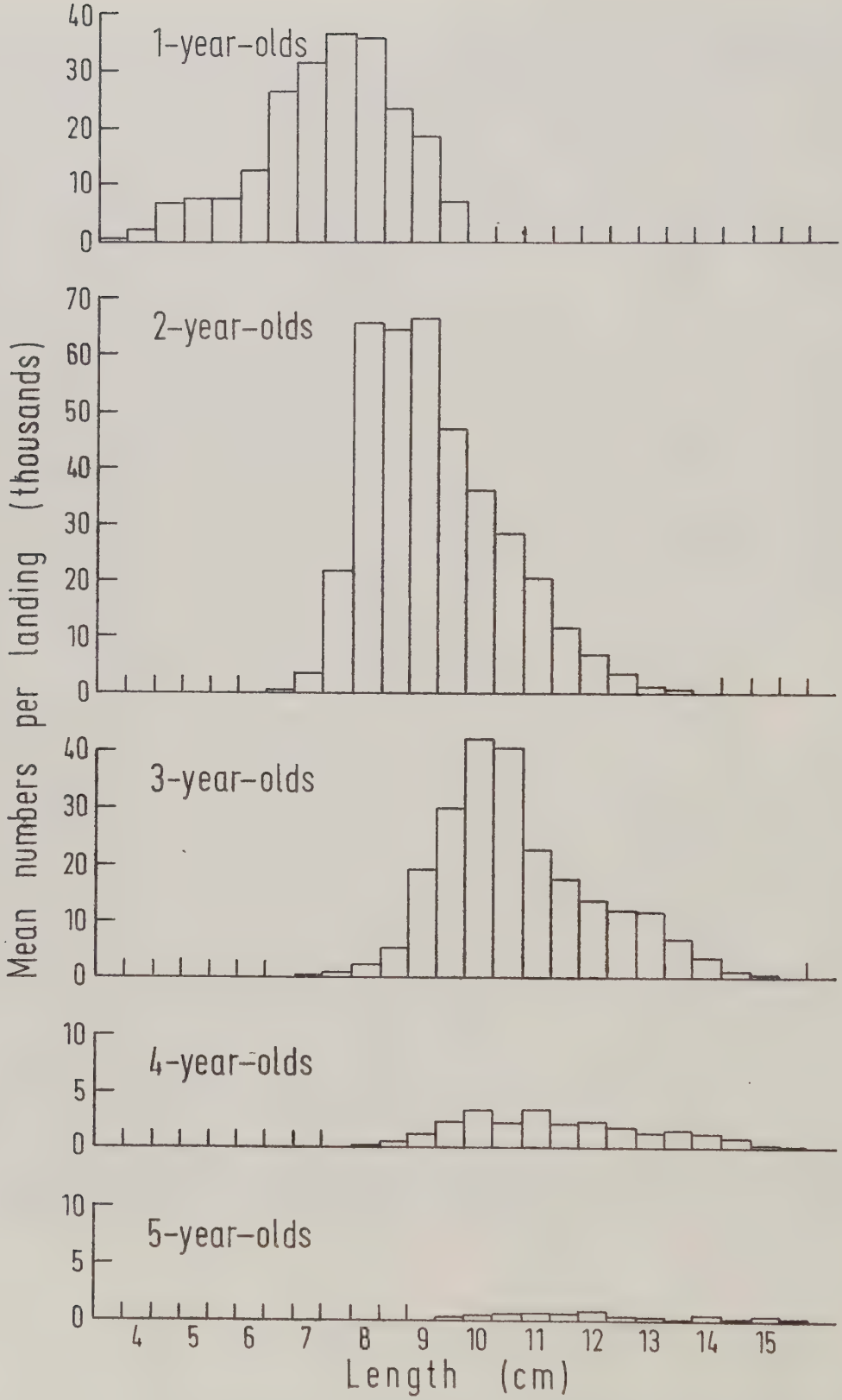


Figure 14 Overall mean length distributions for each age-group in the Wash sprat fishery for 1958 to 1967.

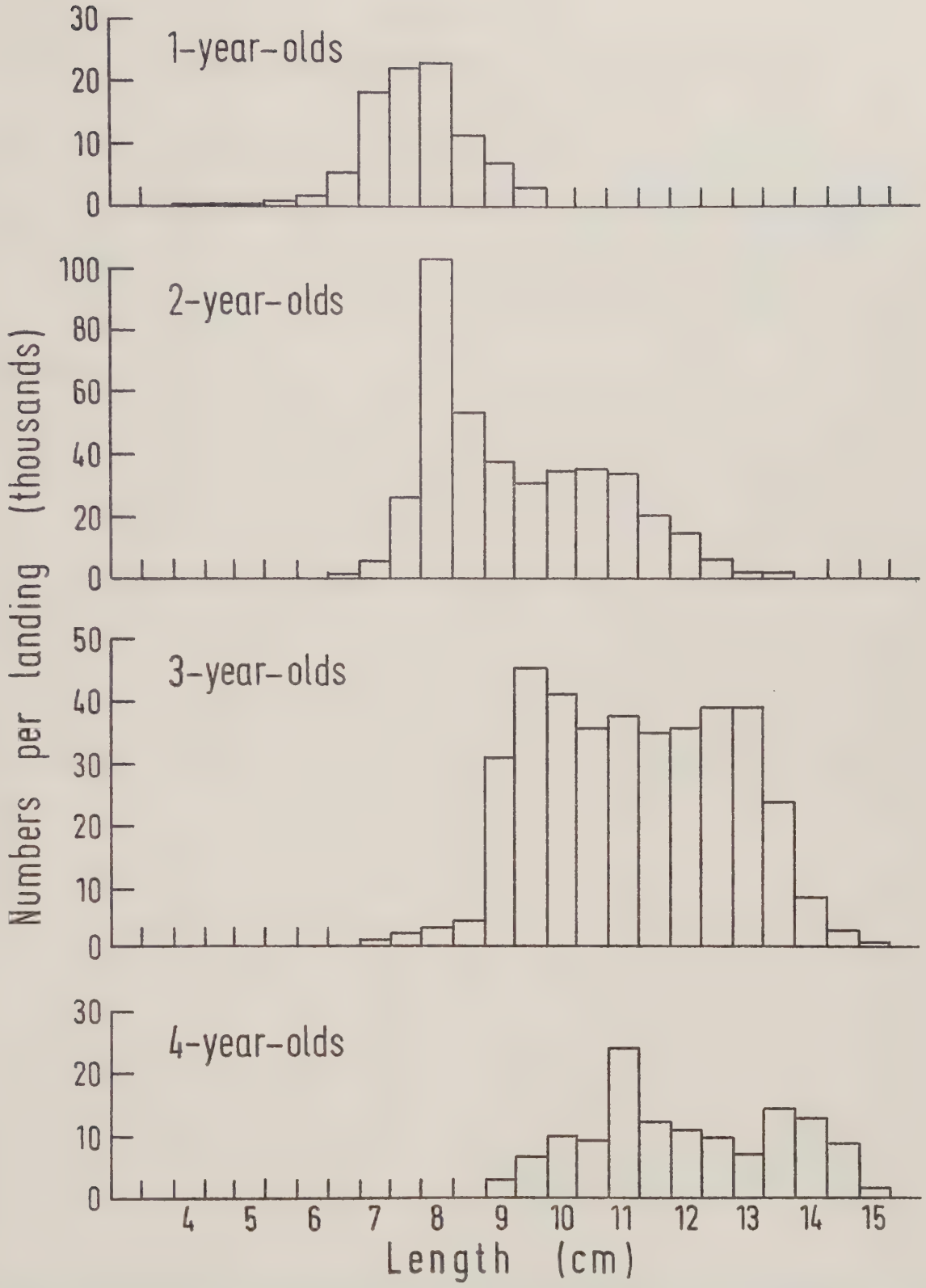


Figure 15 Length distributions of each of the age-groups one to four for the 1961 year-class in the Wash sprat fishery; age-group one was only partially represented, due to mesh selection.

A METHOD OF ESTIMATING THE MESH SELECTION CURVE FOR SPRATS

The usual method of estimating mesh selection for a trawl net is to determine the proportion of fish in each length group retained within the cod-end, and, by plotting this information against length, obtain a selection curve for the net concerned. This requires data on the numbers and lengths of fish escaping, normally determined by using either a finer-meshed cod-end cover or a special fine-meshed trawl comparatively fished with the standard gear. Information of this nature is not available for the sprat fishery, but the above comparison of length distributions for first-year fish in the 1958 year-class (Figure 16) should also provide a means of estimating the degree of mesh selection in each size group (assuming that over the selection length range all length groups were equally available and proportionately represented on the fishing ground).

The usual mesh size employed in the cod-end lengthening pieces of sprat trawls is 9–10 mm bar, a size found by experience over the years to give in an average season a minimum quantity of 'stickers', i.e. fish which are troublesome to shake from the meshes when the net is brought alongside. Allowing for twine thickness the effective aperture of the mesh used is about 9 mm, which gives a potential circumference of about 3.6 cm, equivalent in terms of fish girth to those in the 7.0–7.5 cm length range, which means that if these are potential 'stickers' then the 50 per cent retention length should be in this neighbourhood. This size group also marks the usual overlap region between large first-year and small second-year fish and is normally a zone of minimum numbers.

The method used involves estimating for each half-centimetre group the percentage retention required to give a length distribution showing ratios between successive length groups similar to those shown by first-year fish in the catch. This provides a measure of the proportion of fish retained in each length group, which can then be plotted in the form of a selection curve. The results are summarized in Table 13 which shows the total l_1 distribution (expressed in numbers per thousand fish in the catch), and a comparison between the calculated and actual catch ratios in the successive length groups. The resultant retention curve plotted from these data is shown in Figure 17, the average length at the 50 per cent retention level being about 6.75 cm. The escape level is very low (less than 7 per cent) for fish above 8.0 cm, and high for fish below 6.0 cm (above 90 per cent).

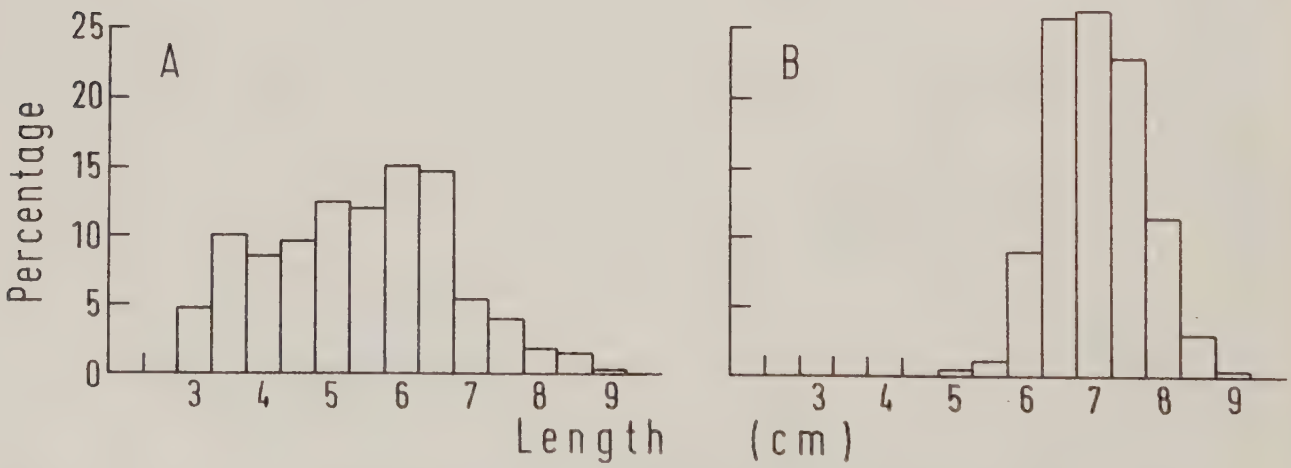


Figure 16 The length distribution of one-year-old fish of the 1958 year-class in the Wash sprat fishery:
A, as derived by back-calculation from the otoliths of two- and three-year-old fish, using a calibration curve of otolith width/fish length derived from otolith measurements made on first-year fish over the length range 2.5–9.0 cm;
B, as obtained from the actual catch.

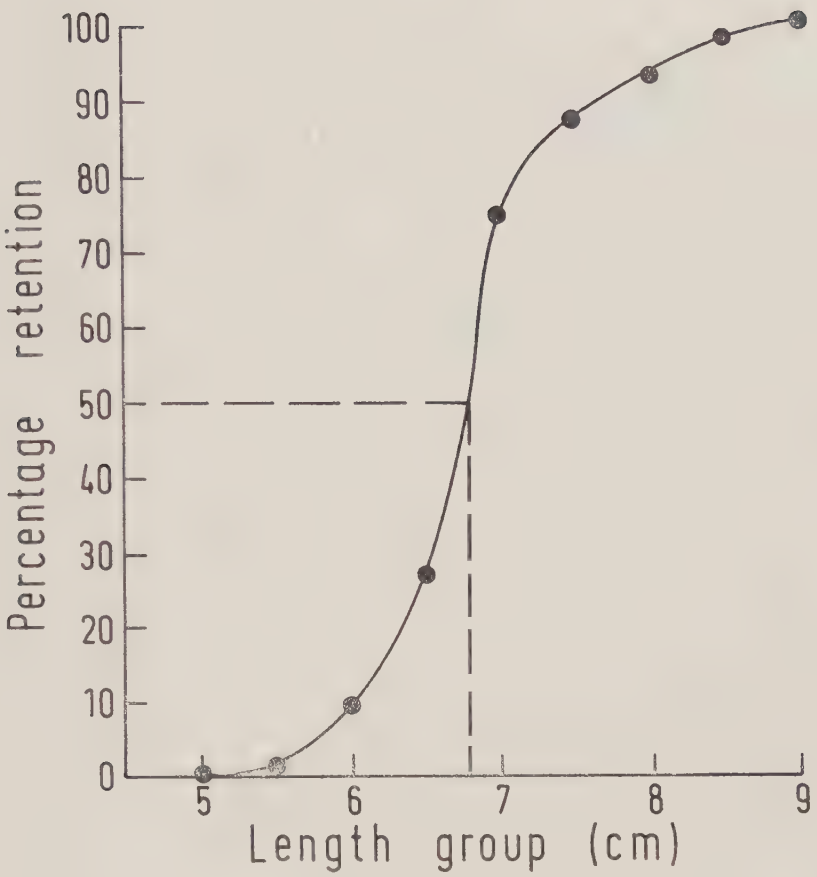


Figure 17 The calculated retention curve for sprats (mesh size 9 mm bar).

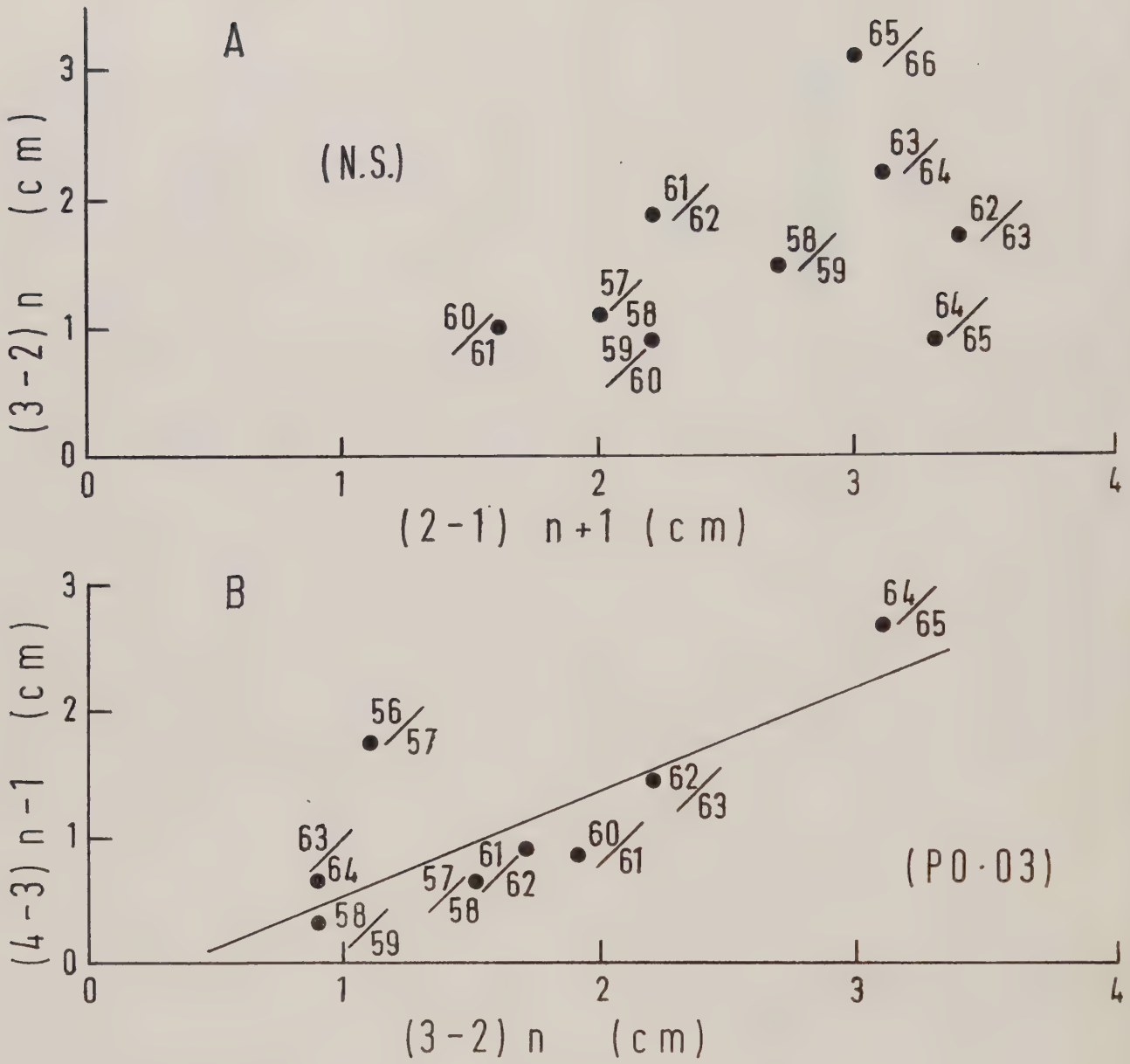


Figure 18 Growth increment relationships in co-existing sprat year-classes:
A, the relation between growth increments of a year-class in the third growth period and those of the neighbouring year-class in its second growth period, i.e. between mature and immature fish.
B, the relation between growth increments of a year-class in the fourth growth period and those of the neighbouring year-class in its third growth period, i.e. between two groups of mature fish.

GROWTH

It is evident from Table 12 that there have been considerable differences between seasons in mean length for age and in the overall growth patterns shown by each year-class in its passage through the fishery. First-year fish are always incompletely represented, and the mean lengths for this group will be larger than the true mean because they are influenced by the numbers and length range of fish above mesh selection size appearing in the fishing area. Second-year fish are probably the most completely represented in the catch, but in the third year there is often a relative decrease in the numbers of larger fish caught which may represent an emigration loss, and can result in a mean length somewhat less than the probable true mean for this age-group. There is a large decrease in representation from the fourth year on and the smaller element only of these older age-groups tends to predominate, the relatively small numbers involved also tending to produce a greater variability in the mean lengths. The histograms of Figure 14 show somewhat skewed length distributions, the skewing occurring in first-year fish towards the upper end of their length range and in older age-groups towards the lower end. The second-year fish show a strong peak between the 8.0 and 9.0 cm groups, the third-year fish between the 10.0 and 10.5 cm groups, whilst fourth- and fifth-year fish are not represented well enough to show well-defined distributions, these being rather flattened over a considerable range of length.

Table 12 also gives the standard deviations of the mean lengths, together with the overall weighted means and maximum ranges in length, for each age-group. There is no indication of systematic differences in standard deviation between year-classes relating to brood size (determined earlier by their relative contribution to the catch shown in Table 10), but there is a trend within most year-classes for an increase in standard deviation with increasing age between two and four years old. The overall mean values show an increase from about 1.2 cm at two years of age to 1.6 cm at four years. Appendix Table B gives the detailed length distributions of different age-groups by year-classes, and this shows that the majority are far from 'normal' in shape, often being highly skewed and sometimes bimodal. The bimodal characteristic could be due to the presence of fundamentally 'slow'- and 'fast'-growing groups of fish (commented on earlier, p. 39), and if the difference in mean length for age between these two components becomes greater with age then this would contribute towards the increased standard deviation noted above.

GROWTH INCREMENTS

The observed pattern of growth within the exploited population has shown considerable variation between year-classes (as is evident from Table 12), this also being reflected in the range of length increments (Table 14). The true growth pattern for the whole population may be very different, particularly if the fishery exploits only a limited portion of this population. Bias could be produced by factors such as mesh selection, partial recruitment, or emigration loss; the latter factor might be responsible for some of the anomalous negative values shown between older age-groups. If the biasses are assumed to be relatively constant errors, any changes in the growth pattern from year to year would reflect genuine changes in the feeding environment, and there might be some association between the annual length increments of different age-groups simultaneously occupying the same feeding area.

In the Wash region there is probably some overlap between the areas occupied by different age-groups during the feeding period, although available evidence suggests that during the later summer months (July to September) the winter fishing grounds are mainly occupied by first- and second-year immature feeding fish, the mature fish then lying further offshore. In this instance the level of association between the growth increments of basically immature and mature age-groups would depend upon the degree to which changes in feeding conditions inshore paralleled those offshore.

Figure 18 compares growth increments between co-existing age-groups. The first part (Figure 18A) compares growth increments in the third growth period (when the fish spawn for the first time) with those of

the neighbouring year-class in its second growth period (while still immature). No relationship is evident, but as the estimates for second-year growth are likely to have a large margin of error due to the incomplete representation of one-year-old fish in the catch, any conclusions must be open to doubt. Figure 18B gives a comparable plot between growth increments in the fourth growth period and those of the neighbouring year-class in its third growth period, both groups representing mature fish. In this case a moderately significant relationship (P 0.03) is evident, which might imply a closer association between these age-groups in terms of feeding conditions or areas.

No comparisons have been made between older age-groups, due to their scarcity in the catch greatly reducing the reliability of estimates for their growth increments.

Table 14 Length increments (cm) between age-groups

Year-class	Age-group (years)			
	2–1	3–2	4–3	5–4
1955	–	–	–	2.3
1956	–	–	1.7	—0.2
1957	–	1.1	0.6	0.1
1958	1.9	1.5	0.3	0.6
1959	2.7	0.8	—0.5	1.3
1960	2.2	1.0	0.8	1.3
1961	1.5	1.9	0.8	—0.8
1962	2.1	1.7	1.4	—0.9
1963	3.6	2.2	0.6	2.3
1964	3.1	0.9	2.6	–
1965	3.2	3.1	–	–
1966	3.0	–	–	–
Mean increment	2.6	1.6	0.9	0.7
Standard deviation of mean	0.6	0.7	0.8	1.2

AVERAGE GROWTH PATTERN

The overall (unweighted) average values of length from Table 12 are shown both as a general growth curve and as a Ford–Walford plot in Figure 19. A regression line has been fitted to the latter by the least squares method and gives an estimate for $L\infty$ of 13.2 cm and a value for the growth constant (K) of 0.53. However, this growth pattern cannot be regarded as truly representative for the whole population, due to the limitations of sampling by the fishery outlined above. It was also noted earlier that in the first season of the fishery (1958–59) scales were taken from some fish for age determination, and it is of interest to compare a back-calculated growth curve derived from four- and five-year-old fish only (90 fish), this being shown as a broken line in Figure 19.

The back-calculated average length of first-year fish (5.4 cm) is considerably less than the length of those in the catch (7.0 cm), and probably lies nearer the true mean, but the values for older fish do not differ very much from those in the catch (only by ± 0.1–0.4 cm). The value for $L\infty$ is only slightly greater, at 13.4 cm, whilst the growth constant K is somewhat larger at 0.62.

Growth and year-class size Increased density in a fish population can result in decreased growth by producing greater competition for food. Density-dependent growth has been established for a number of fish populations, but is not readily distinguishable from other growth-modifying influences in the environment. Iles (1968 and pers. comm.) has demonstrated an apparent density-dependent growth in the O-group stages at all levels of stock density for both the East Anglian herring and the Pacific sardine. This effect is likely to be more pronounced during the earlier stages of the life history, particularly where the juveniles occupy a more restricted habitat than the adult population, and growth in the first year probably provides the best measure for determining the effects of density dependence. Growth in subsequent years will be more influenced by additional changes in the other environmental circumstances, and unless these remain fairly stable the first-year density-dependent relationships will tend to become obscured.

Information on first-year growth in the Wash sprat was insufficient to permit an analysis of possible density-dependent effects on growth at this age, but the relations between the mean sizes of two- and three-year-old fish and their respective numerical indices of abundance have been calculated (Figure 20). A significant relationship (P 0.02) is evident for the two-year-old fish, the negative slope of the regression showing a trend of decreasing size with increasing abundance. The regression for three-year-old fish also shows a slight negative slope, but it is not a significant one ($P < 0.1$). There is thus some indication of a density-dependent growth relationship in two-year-old fish which is not evident by the age of three years.

Weight/length relationship The weight of a fish is usually nearly proportional to the cube of its length, and this relationship can be expressed in the form $W = al^3$ or more precisely $W = al^n$. The values of the constants in this expression will change at different times of the year, depending on the 'condition factor' of the fish, this being determined by factors such as feeding intensity, stage of maturity, etc. (Hile, 1936, discusses the general background of weight/length relationships in considerable detail.)

The average weight/length curve for Wash sprats for the years 1958–1967, converted to logarithms, gives a straight-line relationship and a resulting weight/length regression of $W = 0.0029 \times l^{3.42}$. This will apply to the winter period when feeding has ceased and the fish are mainly in stage II maturity.

Weight/age relationship A curve relating average weight and age, together with a Ford–Walford plot for weight, are shown in Figure 21. The curve is typical—a slightly asymmetrical sigmoid—with an inflexion point between two and three years old at a weight (8 g) around one-third of the asymptotic value (23 g).

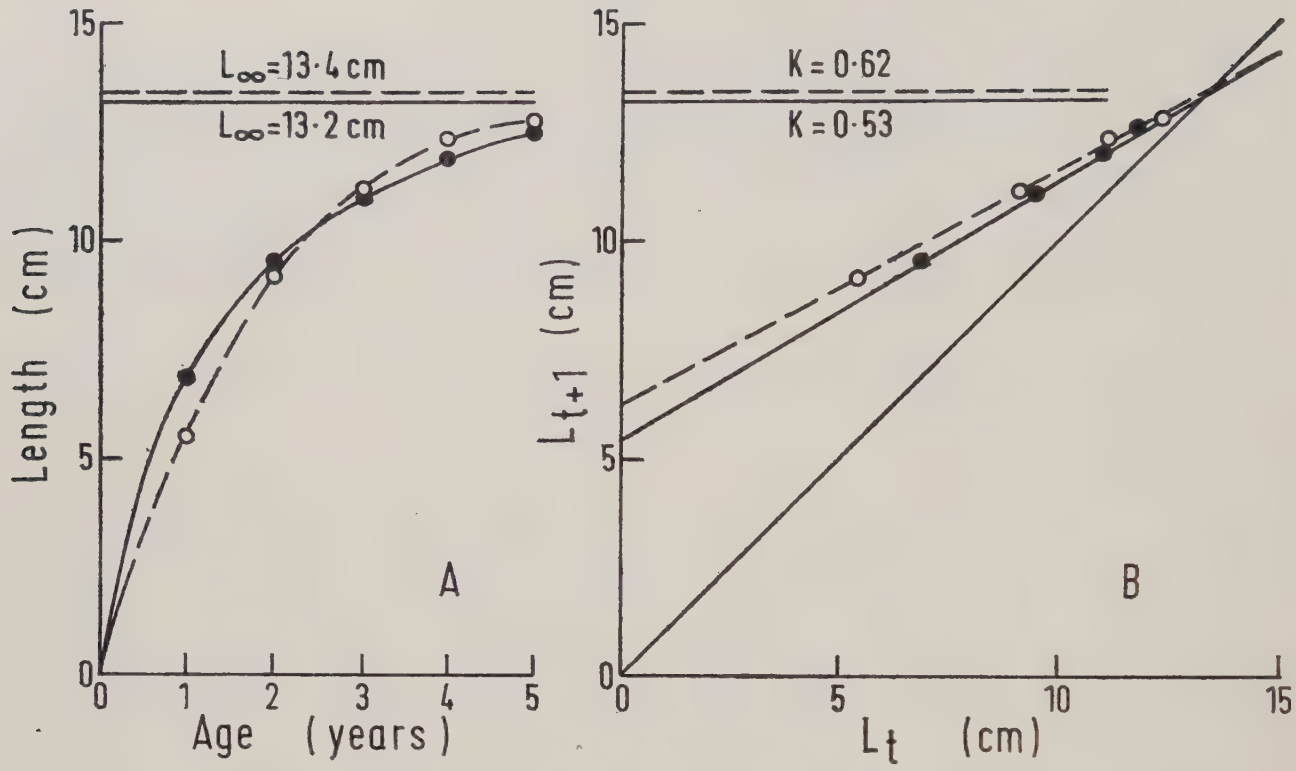


Figure 19 The average pattern of growth in length for Wash sprats:
A, as a general growth curve;
B, as a Ford-Walford plot.
The full lines are those derived from the overall means of Table 12, and the broken lines are the back-calculated growth curves for the 1958–59 season, constructed from the data for four- and five-year-old fish.

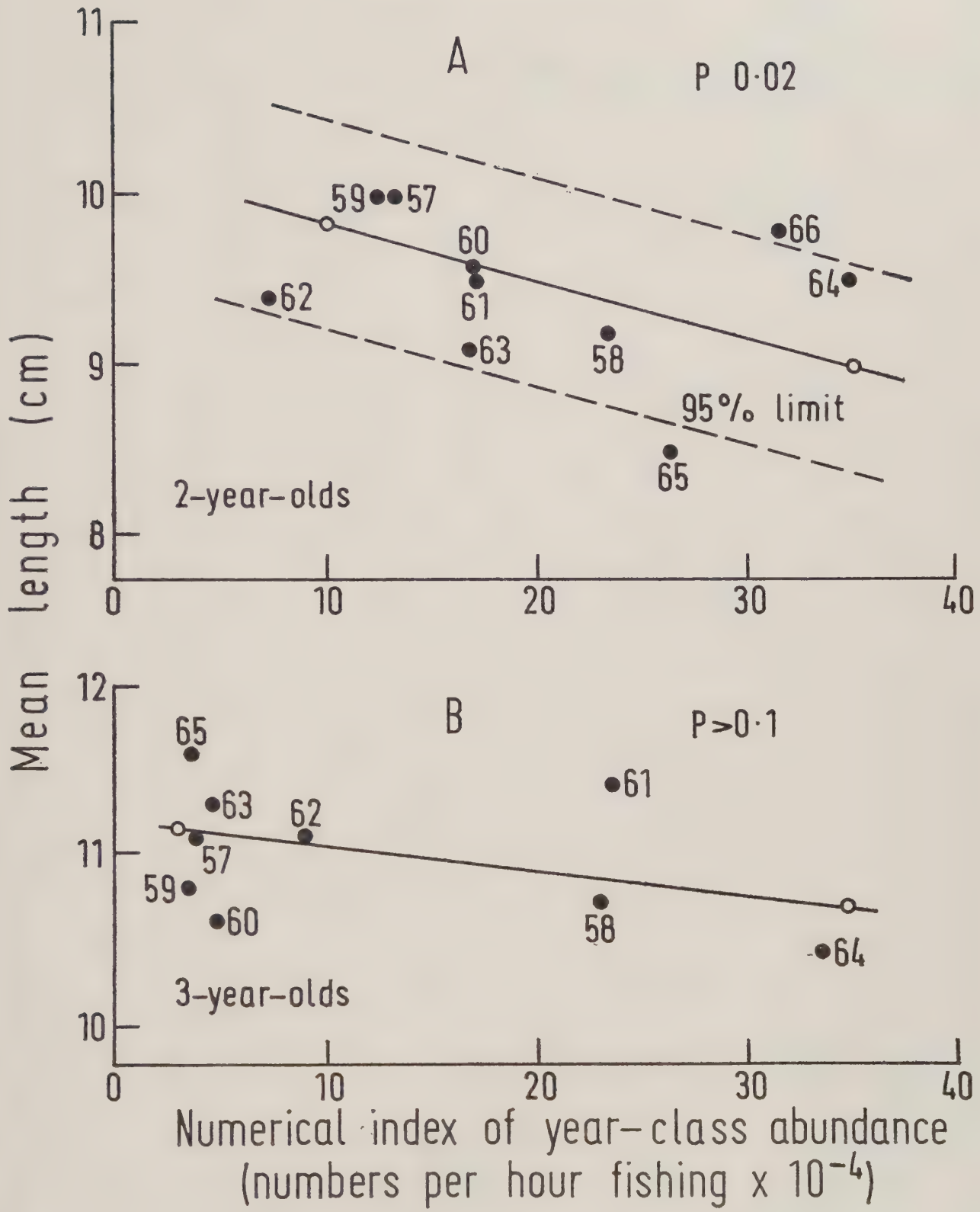


Figure 20 The relation between mean length and year-class size in the Wash sprat.

Table 15 Estimates of the relative biomass of successive age-groups of Wash sprats under conditions of constant and increasing mortality rates with age

(a) Constant total mortality rate between age-groups (Z=0.80)

Age-group (years)	Observed mean weight, $\overline{W}$ (g)	$\log_e \overline{W}$	Relative change of weight, G	(G — Z)	$_e$(G — Z)	'Stock' weight (metric tons)	Equivalent numbers (thousand fish)
1	1.2*	0.18				1.00	833
			1.61	+0.81	2.248		
2	6.0	1.79				2.25	375
			0.55	—0.25	0.779		
3	10.4	2.34				1.75	168
			0.29	—0.51	0.600		
4	13.9	2.63				1.05	76
			0.16	—0.64	0.527		
5	16.3	2.79				0.55	34

* Back-calculated value.

(b) Increasing total mortality rate in older age-groups.

Age-group (years)	$\log_e \overline{W}$	Relative change of weight, G	Observed total mortality, Z (1958–67)	(G — Z)	$_e$(G — Z)	'Stock' weight (metric tons)	Equivalent numbers (thousand fish)
1	0.18					1.00	833
		1.61	0.74*	+0.87	2.387		
2	1.79					2.39	398
		0.55	0.74	—0.19	0.827		
3	2.34					1.98	190
		0.29	1.70	—1.41	0.244		
4	2.63					0.48	34
		0.16	1.89	—1.73	0.177		
5	2.79					0.08	5

* Assumed to be the same for this age interval as for two–three years.

THE RELATIVE BIOMASS OF DIFFERENT AGE-GROUPS

If it is assumed that growth and mortality coefficients follow equivalent exponential functions over fairly short time periods an estimate of the relative biomass of fish in successive age-groups can be made (Ricker 1958). Basically, this method expresses growth and mortality between successive age-groups in terms of exponential coefficients, and applies these to an initial first-year biomass to show the relative change in weight or numbers to be expected as the year-class becomes older.

Table 15 sets out this analysis in two parts, the first representing a situation where the total mortality rate between age-groups remains constant, the second showing an increasing rate of total mortality between the older age-groups, the mortality ratio used in this instance being the mean values observed in the fishery over the period 1958–1967. The mean weights for age used in both cases are those derived from the fishery over the same period. The selected value for the constant rate of total mortality ($Z=0.80$) lies between the overall mean value ($Z=0.74$) determined between two- and three-year-old fish in the catch and an estimated value for the rate of natural mortality ($Z=0.85$) derived from the M/K relationship established by Beverton (1963) for clupeids.

It is clear from this tabulation that under conditions of both constant and increasing rates of total mortality the estimates of stock weight show a relative maximum biomass at the end of the second year's growth. The stock weight becomes reduced from this maximum level by around 20 per cent when three years old, and by 53 and 80 per cent under conditions of constant and increasing total mortality rates respectively when four years old. The equivalent numerical decline is in both cases directly determined by the mortality coefficients used.

It has already been postulated that the observed apparent increase in total mortality for older fish could be largely due to an emigration loss of the larger members. If the natural mortality rate remains constant and the fishing mortality rate is relatively small, then the differences between the two sets of estimates for the stock weight when four and five years old, shown in Table 15, will represent the proportion of older fish lost to the fishery by emigration. This amounts to a weight or number loss of around 55 and 35 per cent for four- and five-year-olds respectively; these values are probably underestimated, due to the relative changes in mean weight between age-groups (G) used in both sets of calculations being derived from the fishery, this sampling only the smaller members of the older age-groups.

This analysis represents a fairly long-term average situation for the exploited stock, but in practice the great variability in year-class strength can produce a relative distribution of co-existing age-groups very different from the above pattern. In some seasons three-year-old fish can strongly outweigh two-year-olds, or even four-year-olds the three-year-olds, depending on the relative magnitude of the broods concerned.

If the reproductive potential is proportional to biomass then the sprat normally spawns for the first time (at two + years) when its age-group biomass is likely to be near a maximum, although the absolute spawning potential will depend on the combined biomass of the individual year-classes making up the spawning stock.

GROWTH AND RECRUITMENT

It was decided to examine the possibility of relationships between growth in the year of spawning and the strength of that brood's subsequent recruitment. The best measure of growth for this purpose would be that shown by a brood in its first year of life, since this directly relates to the brood during a period when its numerical strength is basically established. There was not sufficient information available on the first-year's growth in the Wash sprat for this use, but the growth increment shown by fish in the parental stock during their third growth period (when spawning for the first time) was utilized instead. There are limitations to using growth in this age interval as an indicator of conditions for O-group growth and survival, particularly if the adult and juvenile environments are spatially separated, although if they are not too far removed from each other parallel fluctuations may be shown within each. However, growth in this age interval does involve the two most completely represented and abundant age-groups normally present in the fishery, and the association noted earlier (Figure 18) between this increment and that shown by co-existing three- to four-year-old fish suggests that it can be taken as indicative of conditions within the main spawning population assumed to be immediately involved in maintaining the fishery.

The relationship between year-class strength when recruited (expressed as the numerical catch per unit effort when two and three years old) and the length increment shown in the third growth period by the parental stock is given in Figure 22. Although there is no significant overall relationship ($P > 0.1$) it is possible that the observations could group into two levels of association, as indicated by the broken lines. One involves the very large broods, and the other the average or small broods. Within each there is a trend for increasing strength of recuitment with larger growth increments. However, with so few observations these suggested relationships can at best be speculative, but they do lead to some further interesting analysis.

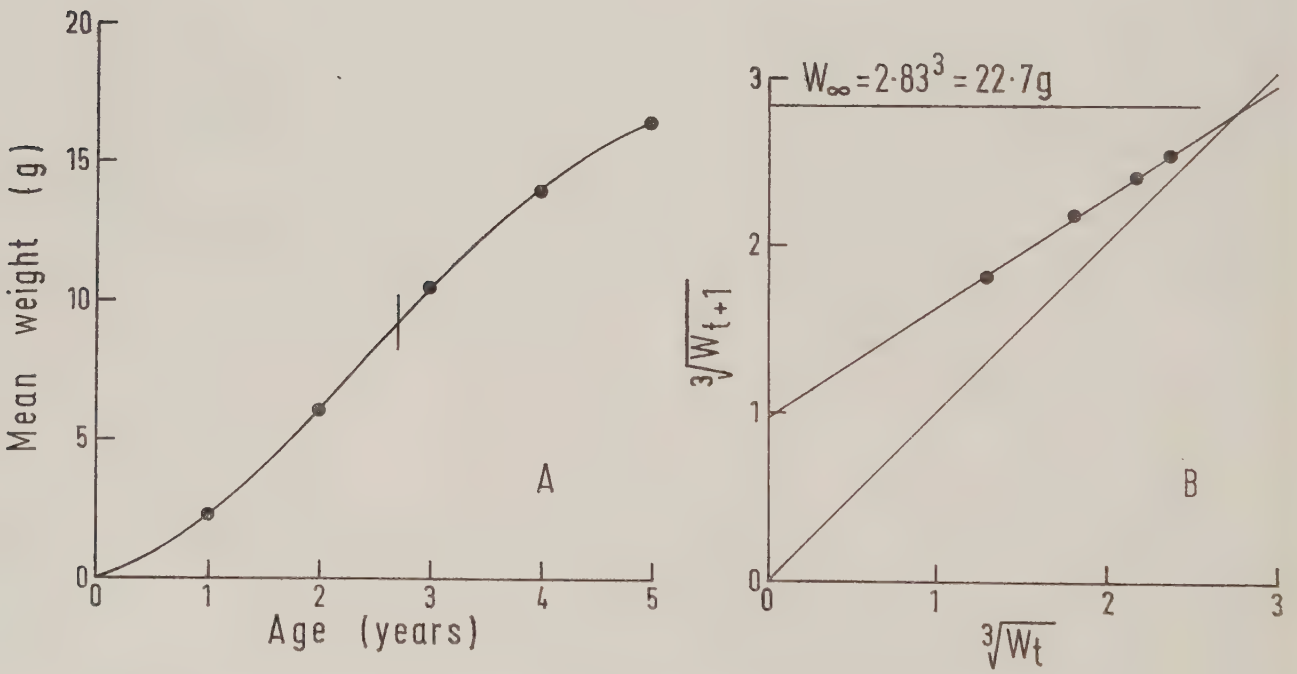


Figure 21 The average age/weight relationship for Wash sprats for the years 1958–1967:
A, as a general growth curve;
B, as a Ford–Walford plot.

The growth increment in this age interval will not only be dependent on environmental feeding conditions during the year but will also be governed by the initial size of fish at the beginning of the growth period. (Intra-year-class relationships of this type have been discussed by Iles (1967) in his analysis of growth in the East Anglian herring.) An inter-year-class comparison between length increments in the third growth period (between two and three years old) and average lengths when two years old is shown in Figure 23. A highly significant ($P < 0.01$) inverse relationship exists, with smaller fish producing a bigger growth increment than larger ones.

Incomplete representation of these age-groups in the catch could also influence growth estimates for this age interval, particularly where the three-year-old fish are concerned. In some seasons there have been indications that a sizeable proportion of the larger members of the three-year-old age-group have not appeared in the fishery. This will reduce the estimate for their mean size, and also underestimate their growth increment. The 1964 year-brood was a specific example of this and its value does fall outside the 95 per cent confidence limits of the regression in Figure 23. However, the main factor contributing towards the variance about this regression is likely to be an environmental one.

This relationship leads to the conclusion that the strength of a recruit brood is thus inversely proportional to the mean size of two-year-old fish in the fishing season prior to the year in which that brood was spawned, this being shown in Figure 24. The underlying causes for such a relationship are not very obvious, but one explanation could arise from an earlier correlation (Figure 20A); this showed a significant relationship between the mean size of two-year-old fish and their indices of abundance. Thus if the mean size of a two-year-old fish is indicative of the size of its year-class (due to density-dependent effects influencing growth), and also the size of the main spawning element in the parental stock, then if strength of recruitment is governed by the size of parental stock this relationship would follow. (This is discussed further in the section on stock and recruitment.)

This still leaves the problem of the postulated two-level association, the values for strength of recruitment in large broods being well outside those for average and small ones. This could be explained by the large broods being composed of an admixture of fish from two calendar years' spawning (noted previously), whereas the average or small broods are not augmented, or only slightly so, by a concealed component.

If this relationship is confirmed by future observations it could prove a very useful one for predicting the likely strength of recruitment two years ahead, although further information is needed to clarify the situation, particularly the circumstances likely to give rise to the very large broods. It is of interest to note that the mean size of two-year-old fish in the 1966–67 season was only 8.5 cm (the lowest yet recorded), and the evidence available to date points towards the 1967 year-brood as being a very large one, with a widespread distribution in the central and southern North Sea at least (Johnson 1968*b*).

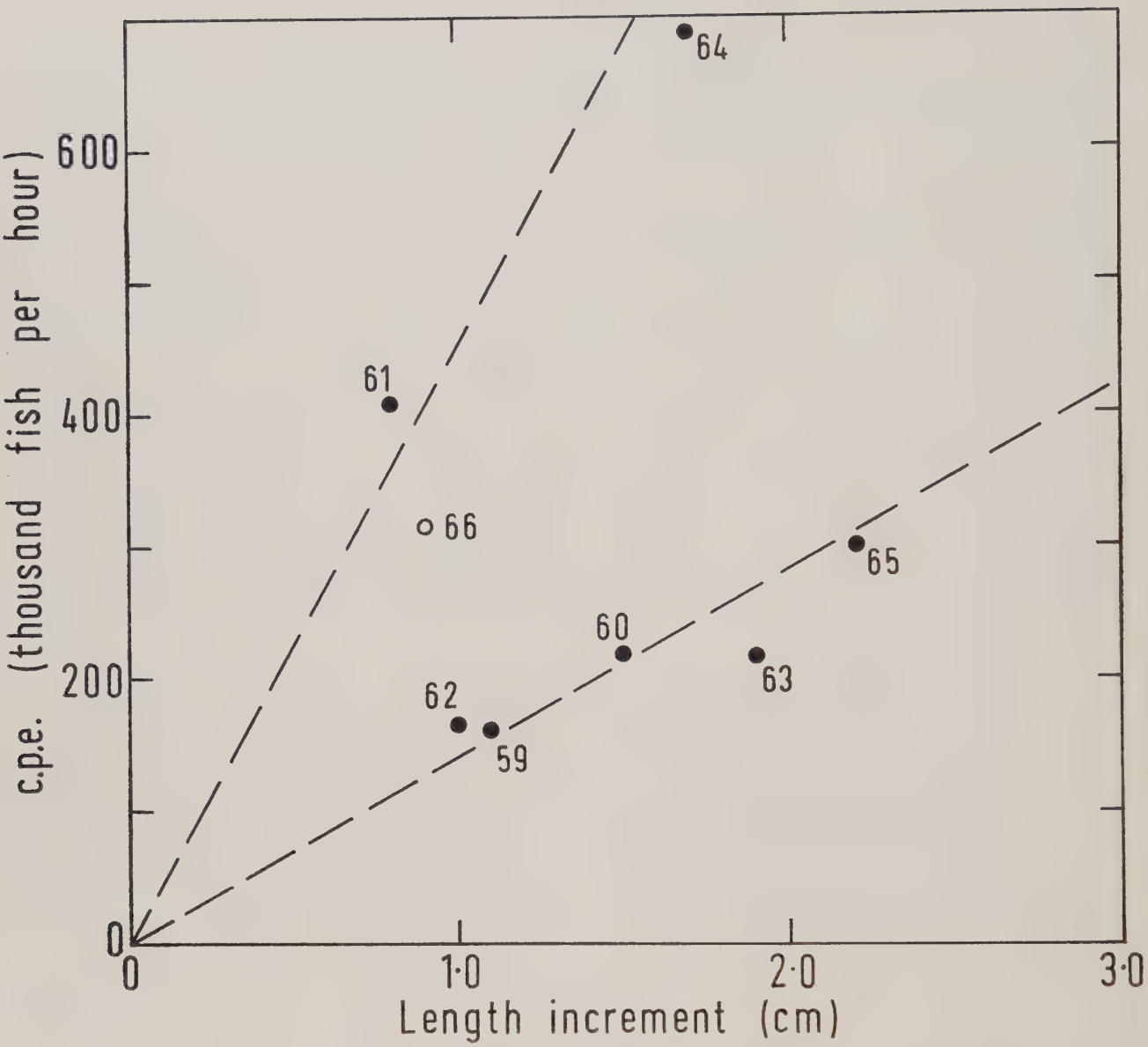


Figure 22 The relation between year-class strength when recruited (as catch per effort of two- and three-year-old fish) and the length increment of the parent stock in the third growth period (1966, two-year-olds only).

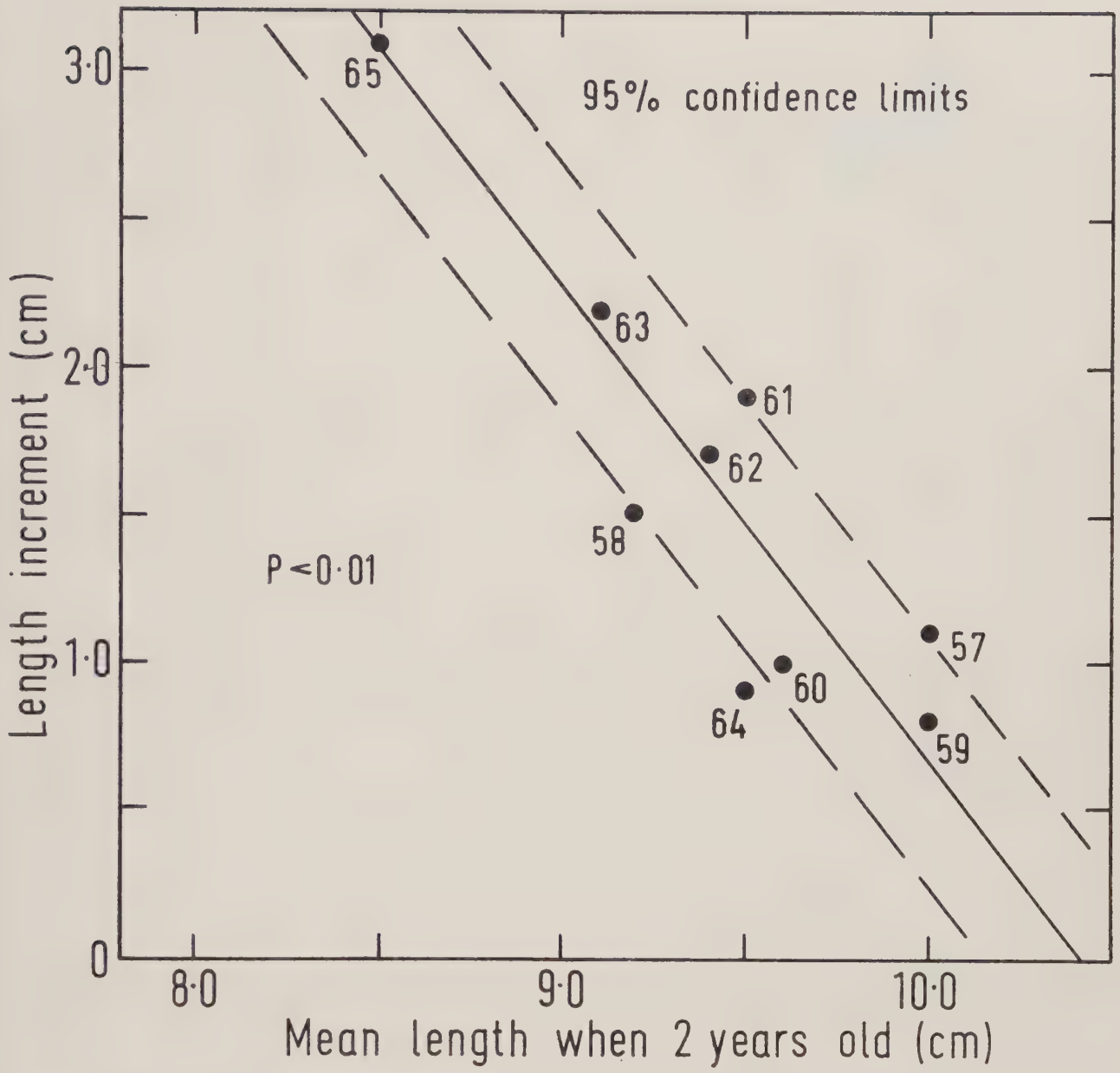


Figure 23 The inter-year-class comparison between length increments in the third growth period and the average length of fish when two years old.

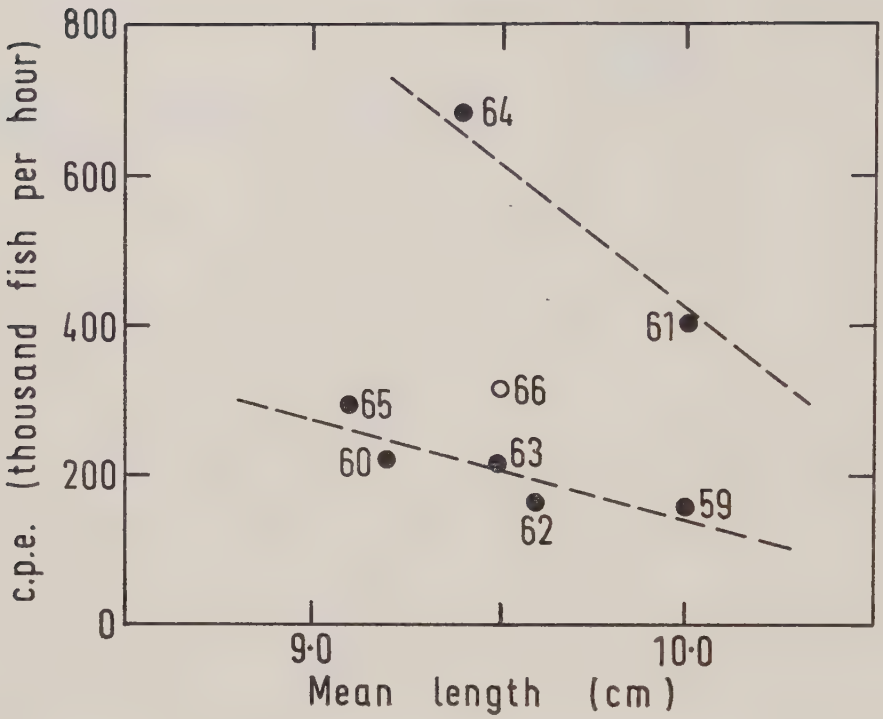


Figure 24 The relation between year-class strength when recruited (as catch per effort of two- and three-year-old fish) and the mean length of two-year-old fish in the parental stock during the fishing season prior to spawning (1966, two-year-olds only).

MORTALITY

General considerations of the sprat population structure indicate that under entirely natural conditions this species probably has a high mortality rate. It is a small fish and thus potentially vulnerable to a wide range of predators, is fairly short-lived, matures early, and has a high fecundity and a high rate of growth.

An approximate estimate of the total mortality coefficient can be obtained from the average age or length of fish present in the exploited population, the following expressions (from Beverton and Holt 1957) showing the relationships involved:

(i) *Age*

$$Z = \frac{1}{\bar{t} - t_c},$$

where Z = total mortality coefficient,
$\bar{t}$ = average age of fish in the catch,
t_c = average age of fish on entry into the catch.

The average values for Wash sprats over the period 1958–1967 are $\bar{t} = 2.12$ years and $t_c = 1.28$ years, which, when used in the above expression, give an estimate of $Z = 1.19$.

(ii) *Length*

$$Z = \frac{K(L\infty - \bar{l})}{\bar{l} - l_c},$$

where Z = total mortality coefficient,
K = growth constant,
$L\infty$ = asymptotic length,
$\bar{l}$ = average length in the catch,
l_c = average length of fish on entry to the catch.

Again, using the average values $K = 0.53$, $L\infty = 13.2$, $\bar{l} = 9.2$ and $l_c = 7.5$ in this formula gives $Z = 1.25$. These estimates thus indicate an average total mortality of about 71 per cent per annum (assuming that it is constant for all age-groups).

YEAR-CLASS ANALYSIS OF MORTALITIES

Another method of estimating mortality is to use indices of abundance (catches per unit of effort) of a given year-class over relatively short periods (usually annual intervals), which will provide survival ratios from which mortality coefficients can be derived using the expression:

$$Z_t = \log_e \frac{\bar{N}_0}{\bar{N}_1},$$

where $\bar{N}_0$ and $\bar{N}_1$ represent the mean abundance indices at the beginning and end of a time period t, here equal to one year. This method gives the mortality estimates shown in Table 16, the catch per unit effort used in these calculations being the numbers of fish caught per hour's fishing by standard 40-foot pair-boat units.

It is clear that there is a great deal of variation between these values of Z, and in the interval between two and three years of age (the most abundantly represented age-groups in the fishery) the very large or large year-classes (1958, 1961, 1962 and 1964) show very little mortality or even none, whereas the weaker broods give much higher values, all of similar magnitude to each other.

Table 16 Total mortalities (Z) between successive age-groups of Wash sprats

Year-class	Age-group		
	2–3	3–4	4–5
1956	–	2.29	0.22
1957	1.28	0.81	2.70
1958	0.03	1.45	1.58
1959	1.27	0.34	1.96
1960	1.27	0.60	3.08
1961	—0.32	1.70	2.70
1962	—0.19	2.59	0.40
1963	1.27	1.71	2.51
1964	0.04	3.81	
1965	1.99		
Means	0.74	1.70	1.89

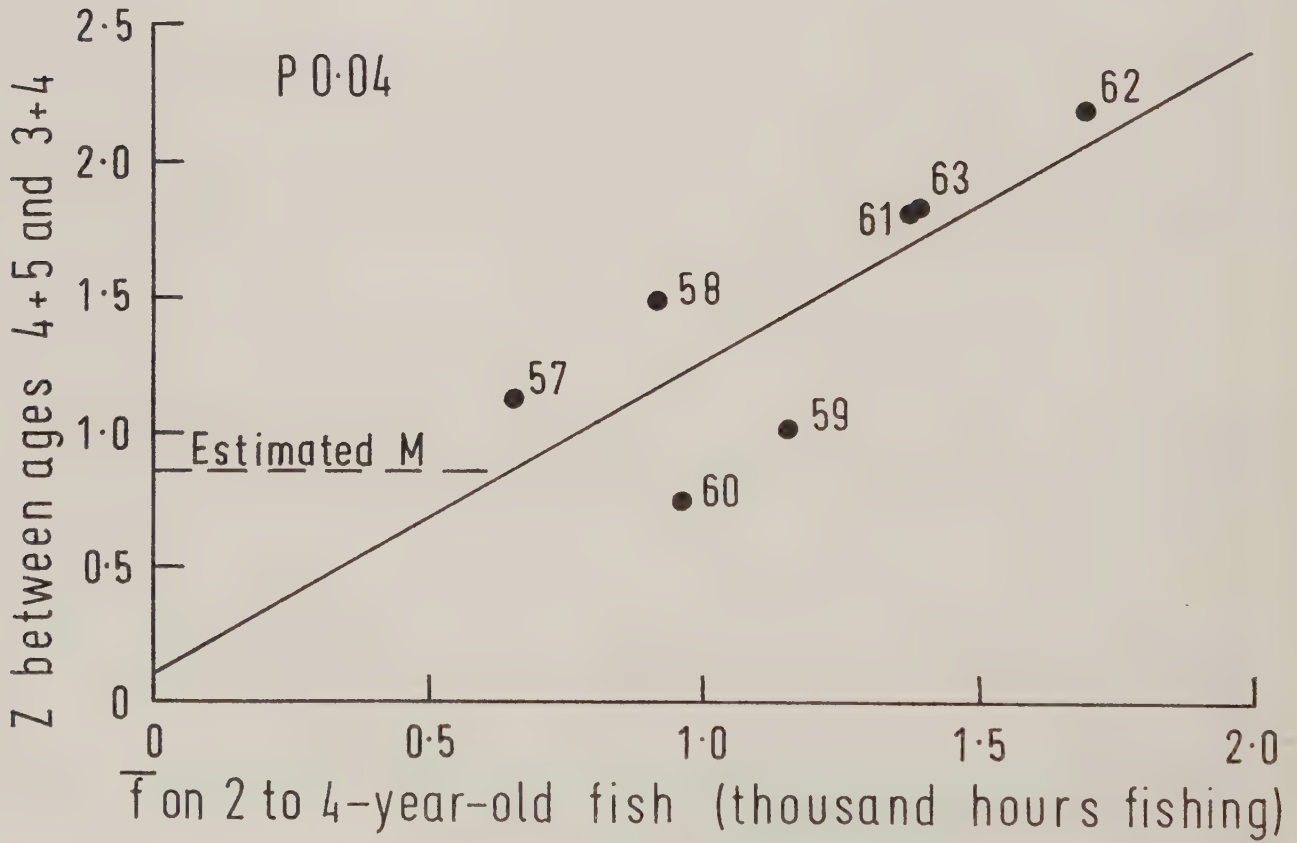


Figure 25 The relation between the average total mortality coefficient over the age-range three to five years and the mean fishing effort over the age-range two to four years.

EFFECTS OF PARTIAL RECRUITMENT AND SATURATION FISHING

These variations in mortality between year-classes could be produced by a situation of partial recruitment of younger fish resulting in two-year-olds being incompletely sampled, or they could be due to the measure of catch per unit of effort employed not being a valid indicator of change in abundance at high stock densities. A brief consideration of the background to the stock and the fishery follows, to illustrate how either of these factors might operate in relation to it.

The fishing ground is actually a fish assembly area, whose dimensions and density are basically governed by the quantity of fish moving into the region. If this area had a fixed boundary then any increase in population would register directly as an increase in average catch-rate, but if there was an upper limiting population density then any increase beyond a certain level would result in an increase in the size of the assembly area, without any further proportionate increase in catch-rate. Indirectly the average catch-rate might improve due to the increased size of the assembly area improving the chances of locating fish, especially when fishing effort is rather limited. The exceptionally abundant broods of 1958, 1961 and 1964, which registered an apparent zero mortality between the ages of two and three years, might have still been sufficiently numerous at three years of age to exceed the upper limiting density and thus produce saturation level catch-rates at both ages.

Situations on the fishing ground resulting in partial recruitment for the smallest fish could result from mesh selection, from reduced vulnerability due to behavioural differences (e.g. a tendency to swim closer to the surface above the main fishing depth), or simply from differences in distribution, as in the case where the nursery grounds are separate from those of the adults.

It was shown earlier that the 50 per cent mesh retention level for sprat was around a length of 6.75 cm, with almost complete retention above 8.0 cm. This length range represents the lower tail end (about 7 per cent) of the average length distribution for two-year-old fish, and it has been estimated, using the mesh selection ogive (Figure 17), that only about 3 per cent by number of this age-group would escape capture, assuming that all the two-year-olds were present in the fishing area and available to the gear. There is some evidence for vertical stratification by size, smaller fish tending to be closer to the surface, and this sometimes results in a double-layered echo trace. Whitebait-sized sprat (4.0–7.0 cm) are often found very close to the surface, particularly in turbid water, and they may then be above the recording zone of the echo sounder. However, the majority of fish in this size range are first-year, and the proportion of two-year-old fish evading capture in this way is likely to be very small.

If we are dealing with a relatively self-contained stock passing its whole life-history within a restricted area adequately covered by the fishery, then recruitment will basically equate with growth. If growth remains fairly stable and, at the time of the fishery, mesh selection size coincides with the upper and lower minima of two slightly overlapping age-group length distributions, then a situation of partial recruitment on an age basis is not likely to arise. The sprat fishery takes place in winter when the fish are fasting and growth has probably ceased or is minimal, so that from the growth viewpoint recruitment will have virtually ceased when the fishery commences. However, if the stock is not isolated but shows some degree of interchange with neighbouring populations, and if the nursery areas are separated topographically from the main adult fishing grounds, then another aspect of recruitment involving movement of fish from, say, the nursery area to the fishing area will be likely.

Egg surveys indicate that the Wash stock is not entirely isolated, and although early in the spawning season egg densities may be greatest in the immediate vicinity of the fishing grounds, spawning later becomes much more extensive over a considerable offshore area, this probably coinciding with the gradual dispersion of the overwintering concentrations. The fish concentrating seasonally in the Wash area probably represent a good proportion of the stock available within a fairly wide radius from the estuary, which acts as a focal point of aggregation for fish from a much larger 'feeder' area. Extensive whitebait grounds are known to exist close to the fishing grounds, particularly off the Lincolnshire and north Norfolk coasts and probably in all the suitable shallow water bordering the main Wash Estuary. The region is particularly favoured in this respect, with some 365 square nautical miles of water in the depth range 0–6 fm (at low water of spring tides) between the Humber entrance and Blakeney Point. Furthermore the pattern of residual water movements in the area seems likely to assist the aggregation of early stages of fish. The

whitebait grounds overlap to a greater or lesser extent with the main deeper-water sprat areas, because there is usually a small proportion of whitebait present in the catches, this proportion rising when fishing shifts into shallower water regions. Whitebait sprats are to be found inshore for most of the year and their length distribution does not vary a great deal, probably due to movement offshore into deeper water once they reach a certain length (around 7 cm). When the very abundant year-broods (1958, 1961 and 1964) were present as first-year fish (O-group), more and bigger whitebait were caught on the main fishing ground with the adult fish. If the whitebait grounds in the immediate vicinity of the Wash are not the sole source of recruitment into the adult fishery, then a year-brood might show relatively increased representation as it grew older, through fish originating from other nursery areas.

The apparent lack of mortality shown by the 1962 year-class between two and three years of age could have involved a partial recruitment effect of this type. It was very weakly represented in the catches in its first year, made a better showing in its second year (although it was then co-existing with three-year-olds from the very abundant 1961 year-class, which could have reduced its representation in the catch), and finally made its strongest appearance when three years old, but then turned up mainly on the Lincolnshire coast ground together with immature herring of a similar size range. This year-brood also showed the same sequence of events in the Thames sprat fishery, but on a much larger scale. A point of interest concerning this brood is that it passed its first winter (1962–63) during a period of exceptionally low water temperatures, but it is not known whether this had any bearing on its subsequent distribution.

The total mortality estimates (Table 16) do show a trend of apparent increase in mortality as the fish become older, possibly due to a process of emigration, the older fish moving offshore. Samples of sprat taken well offshore often contain fish that are much larger in average size for a given age and also show a greater proportion of older fish (Johnson 1968 *a* and *b*). In this context it has already been noted that the Wash area had not been exploited for about thirty years when the fishery recommenced in 1959; even so, in that first season fish beyond the age of three years were only sparsely represented in the catches, which suggests that the relative scarcity of older fish could not then have been due to fishing mortality.

In an exploited population total mortality is made up of two components, one being due to natural causes (such as predation, disease, old age, etc.) and the other to fishing. Natural mortality is difficult to estimate directly, although in a lightly-exploited population it may be assumed that most of the observed total mortality is due to natural causes (excluding the complications of partial recruitment and emigration). However, some idea of the magnitude of natural mortality may be obtained from the growth pattern of the species involved. Beverton and Holt (1959) and Beverton (1963) showed that within related groups of species the natural mortality coefficient M is proportional to the growth constant K, so that the faster a fish grows the higher its natural mortality rate is likely to be. In the case of sprat this relationship was $M=1.6K$, and using the average value of $K=0.53$, determined for the Wash sprats, this gives an estimate of M of 0.85, which represents a natural mortality rate of about 57 per cent per annum. This result supports the conclusion that a high natural mortality rate would be consistent with the general population structure and background of this species. It is also similar in magnitude to the overall average value of Z (0.74) between two- and three-year-old fish (Table 16).

CHANGES IN FISHING EFFORT AND TOTAL MORTALITY

There has been an overall increase in fishing effort since the fishery commenced in 1959, and although the close relationship shown between increasing effort and total catch (Figure 8B) implies that to date the fishery has had no measurable effect on the total yield of the stock, Table 9 suggests a decline in the contributions made by four- and five-year-old fish in more recent seasons. This might be due to a progressive reduction in availability of these age-groups or might be connected with the increase in fishing effort. Table 17 gives the average (unweighted) catch per unit of effort for the two- to five-year-old age-groups inclusive over the first and second five-year periods of the fishery; also shown are the mean level of fishing effort and the total mortality coefficients (Z) between age-groups for each period. These values of Z represent average within-season estimates between co-existing age-groups, as compared with the between-season estimates for individual broods shown in Table 16.

The average fishing effort shows an increase of about 1.7 times between the two periods, compared with an increase of nearly 1.5 times in the total mortality coefficient over the age interval three to five years. On the other hand little change in mortality is shown over the age interval two to three years. There is also some indication of this trend within year-classes when the average total mortality coefficient over the age-range three to five years is compared with the mean fishing effort over the age-range two to four years (Figure 25), although the level of significance is small (P 0.04).

Nevertheless, even if increased fishing effort has produced a measurable decrease in the numbers of four- and five-year-old fish this will have little effect on the yield of the fishery, since the major part of the fishable stock usually consists of younger fish. The fishery is essentially a recruit one, and fishing effort will have to attain a level which directly influences recruitment before its effect on the younger age-groups becomes apparent.

Table 17 Catch per unit effort, fishing effort, and total mortality in the Wash sprat fishery in the two five-year periods since it began

5-year period	Catch per unit effort (thousand fish per hour's fishing)				Fishing effort (hours)	Total mortality (Z)		
	Age-group					Age-group		
	2	3	4	5		2–3	3–4	4–5
1958–62	167.7	104.8	25.9	5.7	846	0.47	1.40	1.51
1963–67	233.7	149.1	18.4	2.6	1 469	0.45	2.09	1.96

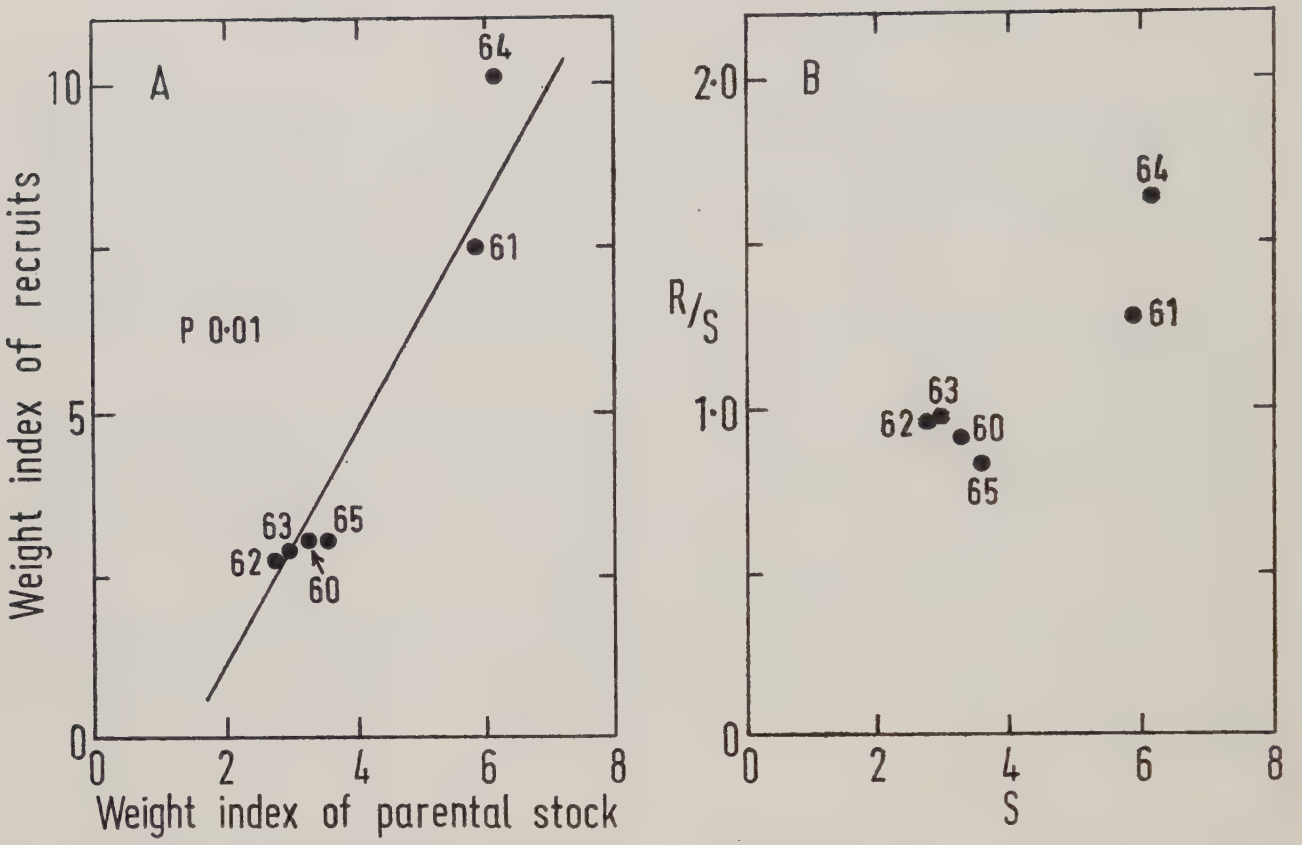


Figure 26 Stock and recruitment relationships for two- and three-year-old fish:
A, the relation between the weight of the recruit brood and the weight of the parental stock;
B, the relation between the progeny/parent ratio, R/S, and the parent stock, S, using weight indices of abundance.

STOCK AND RECRUITMENT

A valid stock and recruitment relationship can only be established if the population sampled by a fishery is in fact a self-contained stock, or a sub-population undergoing comparable fluctuations with a larger total population of which it is a part. A brief discussion of the general background to the North Sea sprat population will show the degree to which these conditions are likely to be fulfilled.

The distribution of sprat within the central and southern North Sea appears to be virtually a continuous one, particularly during the summer months when they are spawning and feeding. Localized aggregations are usually only evident during the late autumn and winter months. The overwintering concentration areas show a remarkable constancy in location from year to year, inshore near large river estuaries or coastal sand-bank systems, and offshore in deeper-water pits and gullies. The problem is whether or not these overwintering patches represent true sub-stocks, which can maintain an identity from generation to generation, or whether they are composed of a fortuitous mixture of fish without common parental stock origins. If these overwintering concentrations are interpreted as pre-spawning aggregations, the areas they occupy do not represent the main spawning regions. Evidence from spawning surveys shows that although early in the spawning period there may be signs of locally high egg or larval densities which can be associated with specific overwintering patches of fish, later on these disperse and merge with neighbouring patches to lose their identity. Subsequent dispersion and mixing of the spawning product with equivalent stages from neighbouring spawning groups does create a difficulty for the future maintenance of identity with parental stocks. It is difficult to envisage a segregation mechanism which would allow homing to the original place of spawning in this situation.

The strength of recruitment to a particular overwintering area may be dependent on the quantity of O-group fish originally establishing themselves in the immediate vicinity, the immature phase of development over the first two years involving a fairly static population. If, during this period, an 'affinity' for a particular estuary or river system develops this could lead to adult fish showing 'homing' behaviour by returning to the overwintering grounds nearest their nursery areas. Conversely, it may be argued that the location of overwintering grounds is a consequence of the dispersion pattern and accumulation sites for the young stages. This implies that when part of a year-class becomes established during its early stages within a particular area, it will then tend to remain in close association with that area for the remainder of its life. Thus, some degree of sub-stock isolation would operate in the adult fish only, but would not necessarily apply to their spawning products. However, it is possible that some estuarine overwintering populations may be self-maintaining to some extent, depending on the pattern of residual currents and their relation to the spawning area and dispersion or accumulation of the young stages. The pronounced onshore drift pattern of the Wash area might ensure that a major part of the future recruitment will be derived from pre-spawning winter aggregations accumulating in the vicinity.

There can be considerable variation in the actual contribution a given year-class makes in different fishing areas, even when these are not too widely separated. For example, the 1958 year-class, whilst making a strong appearance in the Wash fishery, was only poorly represented in the Thames area. On the other hand, the 1961 year-class appeared in great strength all around the coastline from Scottish waters to the south-west coast of England, and the 1964 year-class also made a similar strong appearance except for the Thames area and south coast of England. It is of interest to note that even in the areas where the strong broods did not actually appear in quantity, they were still relatively strongly represented in the catch compared with the other age-groups present.

Once a year-class has become strongly established in a fishery it can usually be relied upon to produce above-average catches in two or more seasons, often still making a useful contribution when four years old, as was the case with the 1958 brood in the Wash fishery. However, there is a further complication in estimating the potential yield of a year-class after assessing the strength of its initial recruitment and that is emigration loss of larger, older fish (shown by an apparent sudden increase in total mortality beyond the age of three years). This is particularly marked in the shallow-water fisheries of the Wash and Thames, and sometimes, as in the case of the 1964 brood in the Wash fishery, an unexpected loss of this type can occur

at three years of age, this reducing the representation of the brood below that expected from its strength in the previous year.

The degree of interchange of older fish between adjacent fishing areas is not known; the only instance to date where this has occurred on a large scale concerned the 1962 brood in the Thames and to a lesser extent in the Wash fisheries, which was commented upon earlier (p. 62).

The information provided by a particular fishery on the stock and recruitment situation could obviously be readily influenced by any of the above factors introducing an extra element of variance totally unrelated to any intrinsic relationship that may exist. Nevertheless, it was decided to examine the available evidence from the Wash sprat fishery to determine the pattern of stock and recruitment to date and whether or not it could be interpreted in terms of a specific stock and recruitment relationship.

There has so far been a three-year interval between the appearance of large broods in the Wash fishery (1958, 1961, 1964 and probably 1967). This might be due to a cycle of environmental change resulting in very favourable conditions for survival every third year, or a situation where a large year-class has tended to generate a large brood, in which case there would have been no environmental limitations controlling abundance. The parental spawning stock in the years of origin for large broods has consisted of predominantly three-year-old fish, themselves members of large broods. In the previous year, when these fish made up a predominant two-year-old component of the spawning population, only average or below-average broods apparently resulted. It might thus be concluded that three-year-old fish possess an additional element of spawning efficiency outweighing their relative reduction in spawning potential (i.e. biomass) from the age of two years. However, if large broods are composed of a mixture of fish spawned in two calendar years, then two-year-old fish may in fact be contributing towards the following year's brood if they spawn later in the year, their progeny not being large enough to lay down a recognizable winter ring in their first winter. In the section on analysis of maturity evidence is presented to show that during the fishing season large fish tend to mature earlier than smaller ones, and if this trend is maintained into the spawning period they should also commence spawning sooner. An equivalent age/maturity assessment is not available, but if it is assumed that the larger fish are predominantly older ones and vice versa, then there is a possibility that older fish tend to spawn earlier than younger ones, although further information from the actual spawning period is required to confirm this.

In the following stock and recruitment assessments catch per unit effort by weight is used as a common index of abundance for both filial brood and parental stock. The mean catch per unit effort when two and three years old provided an estimate of recruit brood strength, and that of two- and/or three-year-old fish in the fishing season prior to the spawning period a measure of spawning potential for the parental stock. Figure 26A shows the relationships between recruit brood strength and a parental stock composed of two- and three-year-old fish in the assigned year of origin for the recruit brood. A significant (P 0.01) correlation suggests strength of recruitment increasing with parental stock size. Figure 26B shows the correlation of progeny/parent ratio (R/S) on the strength of the parental stock (S). However, the level of correlation (P 0.03) is dependent on the two large broods of 1961 and 1964, and if these have been augmented by a large carry-over from the previous year's spawning this would invalidate their relationship with parental stock in their postulated year of origin.

ANALYSIS OF MATURITIES

MATURITY STAGING

Maturity staging in fish is intended to provide an estimate of the stage reached in the developmental cycle towards spawning by an individual or the population. No absolute time-scale is available to judge this, and the best procedure is to select the maximum number of conveniently recognizable stages of development to construct a scale of maturities, even though each stage may differ in duration.

Previous work on maturity staging in the sprat has shown little consistency, ranging from attempts to equate with the Hjort system for herring (Robertson 1938) to systems comprising four or five basic categories (Heidrich 1925; Aslanova 1954; Petrova 1960). Robertson later decided that the Hjort system was not practicable for the sprat and regrouped his earlier assessments into a four-category system. Because most of these earlier methods also incorporated measurements of egg diameters within the terms of definition, it was decided to examine afresh the developmental sequences found in the material available and construct a scale of maturities based entirely on macroscopic appearances. This method of staging also has an obvious advantage when handling fairly large numbers of fish in a sampling procedure. The main source of samples has been the commercial fishery taking place between November and March, occasionally supplemented by research vessel hauls outside this period. This has enabled a study to be made of the full cycle of development, but material covering the later stages has been somewhat scanty.

Table 18 defines the maturity categories that have been used, although experience is still an important factor in attaining consistent interpretation. In particular, after stage V definition becomes difficult due to the serial nature of spawning in sprat (Heidrich 1925; Aslanova 1954; Petrova 1960), the eggs apparently being shed in discrete batches, with recovery intervals in between.

CHANGES IN THE DISTRIBUTION OF MATURITY STAGES DURING THE FISHING SEASON

Table 19 gives for each season the weighted percentage distributions of maturity stages in each month sampled, together with an overall mean monthly distribution for the whole ten-year period.

In November and December maturation is very slow, with the majority of fish in stages I/II and II. An increase in the numbers of fish in more advanced stages is evident by January, although even up to the end of February many of the fish are still in stage II. A larger proportion of more advanced stages appears during March and a more rapid phase of development commences. Only a very few fish have been recorded as actually spawning in March, and this has been confirmed by evidence from spawning surveys. The majority of the March samples originated from the early part of the month only, and the proportion of more advanced maturity stages for the month is thus probably underestimated. The more rapid change in maturity between February and March also coincides with the period of fish dispersal and termination of the fishery. It is possible that the fish of the more advanced maturity stages tend to move out of the fishing area, but the egg surveys show that at least during the early spawning period the main spawning area also encompasses the fishing grounds.

Table 18 Sprat maturity stages

Stage	Description
I	Immature; the gonads are very thin and threadlike, occupying only a small part of the body cavity. Sex determination by inspection is very difficult and sometimes impossible at this stage
I–II	First signs of development; the ovary is a thin, colourless, tube-like structure beginning to extend along the body cavity; the testes are similar in size but more flattened and often greyish-white in appearance. The sexes are now more readily distinguishable. This stage is encountered most frequently in large first-year fish (7.0–9.5 cm) and over most of the second-year length range (7.0–12.0 cm) during the winter months
II	Resting phase; the ovary shows no visible structure within and may be colourless or reddish in colour; the testes are firm, flattened, with a greyish-white coloration; gonads of both sexes occupy virtually the full length of the body cavity (distinguishing them from the previous stage), but still show a narrow cross-section
II–III	First signs of more advanced development; opaque yolk-filled oocytes begin to appear within the ovary as small specks, and the testes, although still firm and greyish-white, are beginning to show signs of increased vascularization; gonads of both sexes show an increase in diameter
III	The ovary is now considerably enlarged and entirely filled with opaque yellowish oocytes; the testes have now nearly attained their maximum size but are still firm and white inside
III–IV	Patches of larger translucent oocytes begin to appear in the ovary, and the testes are rather softer and 'milky' when broken
IV	Large numbers of translucent oocytes are now present, giving a very mottled appearance to the ovary which is near its maximum size, showing a smooth shiny surface; running eggs are not yet in evidence. The testes are now at their maximum size and very soft
V	Ovary and testes fully developed; gentle pressure readily produces eggs and milt
VI	Recently spent; ovary small, wrinkled, very red; testes very flattened and thin
VI–II	Recovering phase; ovary gradually becoming smoother and more rounded; testes filling out slightly and becoming firmer

VARIATIONS IN THE RATES OF MATURATION BETWEEN SEASONS

It is evident from the seasonal monthly analysis of maturation (Table 19) that although the general trend of change has been similar over most seasons there have been differences in detail. In some seasons the onset of active development (stage II/III) has been markedly earlier than in others (e.g. January 1959, 1960, 1964 and 1965), whilst in the 1962–63 season it was much later, with far more fish than usual still in stage II in February, but by March the pattern of distribution was much as usual, with the majority of fish in stage II/III. It has been shown for the Baltic sprat (Elwertowski 1964) that after prolonged severe winters spawning is delayed by up to a month or more. If this delay is produced by low temperatures slowing down the maturation cycle, then the between-season differences in Wash sprat maturities might be relatable to differences in water temperature.

Table 20 shows the percentage of fish in stage II/III in January and stage II in February, with the associated water temperatures for the Inner Wash region, the values being tabulated in order of increasing temperature. The January values suggest that, with one exception (1959), when water temperatures were below 4.0°C the proportion of fish in stage II/III was much smaller, whereas the reverse occurred when temperatures exceeded 4.0°C, again with only one exception (1961). The February observations show a very high proportion of fish in stage II for 1963 when exceptionally low temperatures prevailed, but temperatures in the remaining years varied relatively little (ranging between 4.0 and 5.6°C) and no clear-cut relationship is shown between them and the proportion of stage II fish.

It is of interest to note that the spawning surveys showed very few eggs in water below 6°C (a value usually attained in this area between mid-March and mid-April), and if this represents a 'threshold' value for spawning then some adjustment of the rate of maturation by preceding temperature levels could ensure the most advanced fish being ready to spawn when this temperature is reached.

RELATIONSHIPS BETWEEN THE SIZE OF FISH AND MATURITY STAGES

Another factor which could influence the distribution of maturity stages is the size of fish, larger fish tending to show relatively more advanced levels of maturity than smaller ones. This is illustrated in Table 21 which gives, by months, the overall mean lengths of fish in each maturity stage for the seasons under review. In each month there is an increase in mean size with increasing maturity stage, and also, in maturities II and above, a tendency within each stage for a reduction in mean length as the season progresses.

Table 19 Percentage distribution of maturity stages (weighted by numbers per landing) for fish larger than 8.0 cm

Season	Month	Maturity stage								
		I	I/II	II	II/III	III	III/IV	IV	IV/V	V
1958–59	December	–	6.2	82.6	11.2					
	January	7.0	5.3	22.5	40.0	25.2				
	February	–	2.9	19.4	64.1	13.6				
1959–60	November	–	23.5	76.5						
	December	1.5	10.0	87.9	0.5					
	January	0.8	4.3	59.5	33.8	1.0	0.6			
	February	11.7	23.8	63.7	0.4	0.3				
	May	0.5	–	5.9	–	37.5	7.8	47.0	1.2	
1960–61	November	2.3	1.2	96.5						
	January	3.3	2.1	91.9	2.7					
	February	–	–	41.9	42.9	15.2				
1961–62	November	3.9	8.7	87.4						
	December	0.4	6.0	93.6						
	January	2.0	–	97.9	0.1					
	February	–	–	54.1	43.1	2.9				
	March	–	–	17.6	82.4					
1962–63	November	15.2	19.9	64.9						
	December	–	19.7	80.3						
	January	–	5.5	94.5						
	February	–	1.8	94.4	3.8					
	March	–	–	14.4	76.1	9.5				
1963–64	December	2.8	7.3	88.6	1.3					
	January	1.1	20.1	43.7	31.4	3.0	0.5	0.2		
	February	–	7.7	72.5	19.5	0.3				
	March	–	6.2	29.7	50.2	9.7	3.4	0.8		
	April	–	5.0	20.1	54.1	16.2	2.2	2.3		

Table 19 (continued)

Season	Month	Maturity stage								
		I	I/II	II	II/III	III	III/IV	IV	IV/V	V
	November	9.3	39.7	47.6	3.4					
	December	1.6	50.0	45.6	2.8					
1964–65	January	7.2	30.7	42.4	17.0	2.7				
	February	13.4	29.3	39.3	13.1	3.3	1.2	0.5		
	March	9.7	24.0	27.5	18.1	10.7	5.5	3.6	0.8	0.2
	December	6.7	53.2	37.9	1.6	0.5				
1965–66	January	4.9	32.1	58.7	2.9	1.4				
	March	5.7	34.7	50.8	6.9	1.8				
1966–67	November	11.9	52.0	36.1						
	December	–	60.5	32.7	6.8					
1967–68	December	31.5	58.8	9.0	0.3					
	January	39.7	40.8	16.2	2.2	0.8	0.3			
	November	7.1	24.2	68.2	0.6					
	December	4.9	30.2	62.0	2.7	0.1				
Means	January	7.3	15.6	58.6	14.5	3.7	0.2			
	February	3.6	9.4	55.0	26.7	5.1	0.2	0.1		
	March	3.1	13.0	28.0	46.7	6.3	1.8	0.9	0.2	–

Table 20 The association between sprat maturity stages and water temperature

January			February		
Temperature (°C)	% stage II/III	Year	Temperature (°C)	% stage II	Year
2.7	0.0	1963	0.3	94.4	1963
3.2	0.1	1962	4.0	72.5	1964
3.4	40.0	1959	4.2	39.3	1965
3.6	2.9	1966	4.5	54.1	1962
3.9	2.2	1968	4.9	19.4	1959
4.5	31.4	1964	4.9	63.7	1960
4.7	17.0	1965	5.6	41.9	1961
5.7	2.7	1961			
5.8	33.8	1960			

Table 21 Mean lengths (cm) of sprat in each maturity stage in the months November—March, for the period 1958—1967 (fish larger than 8.0 cm)

	Maturity stage								
	I	I/II	II	II/III	III	III/IV	IV	IV/V	V
November	8.5	9.1	10.6	13.0					
December	8.5	9.2	10.9	13.0	14.0	15.0			
January	8.6	9.2	10.9	11.5	12.0	13.0	13.7		
February	8.7	9.1	10.3	11.8	12.1	11.6	12.3		
March	8.6	9.0	9.8	11.1	11.7	11.2	11.2	11.4	13.4

Table 22 Minimum maturation sizes, sex ratios, and percentages of first-year fish in the Wash sprats

Season	Minimum length (cm) for gonadal maturation (all age-groups)	Length-groups 6.0–10.0 cm	
		Ratio ♂/♀	% first-year fish
1958–59	7.8	0.92	65.4
1959–60	7.5	0.59	6.4
1960–61	7.9	0.77	11.2
1961–62	7.3	0.71	16.9
1962–63	7.4	0.83	0.6
1963–64	7.8	1.06	16.6
1964–65	7.9	1.21	14.9
1965–66	7.6	1.01	0.4
1966–67	7.8	1.10	9.4
1967–68	8.7	1.19	76.1
Means	7.8	0.92	21.8

Table 23 Analysis of the relationship between maturity and the proportions of first-year and second-year fish (as thousands of fish per landing and as percentages) in the samples taken during December and January, 1967/68 (length-groups 7.5—9.5 cm)

	First-year fish				Second-year fish			
	Males		Females		Males		Females	
	Nos.	%	Nos.	%	Nos.	%	Nos.	%
Maturity stage								
I	261.5	54.0	365.2	83.3	60.7	32.4	–	–
I/II	218.1	45.2	73.3	16.7	85.2	45.5	113.2	88.2
II	2.8	0.8	–	–	41.2	22.0	15.2	11.8
Total	482.4		438.5		189.1		128.4	
Minimum maturation length (cm)	8.7		9.1		8.8		–	

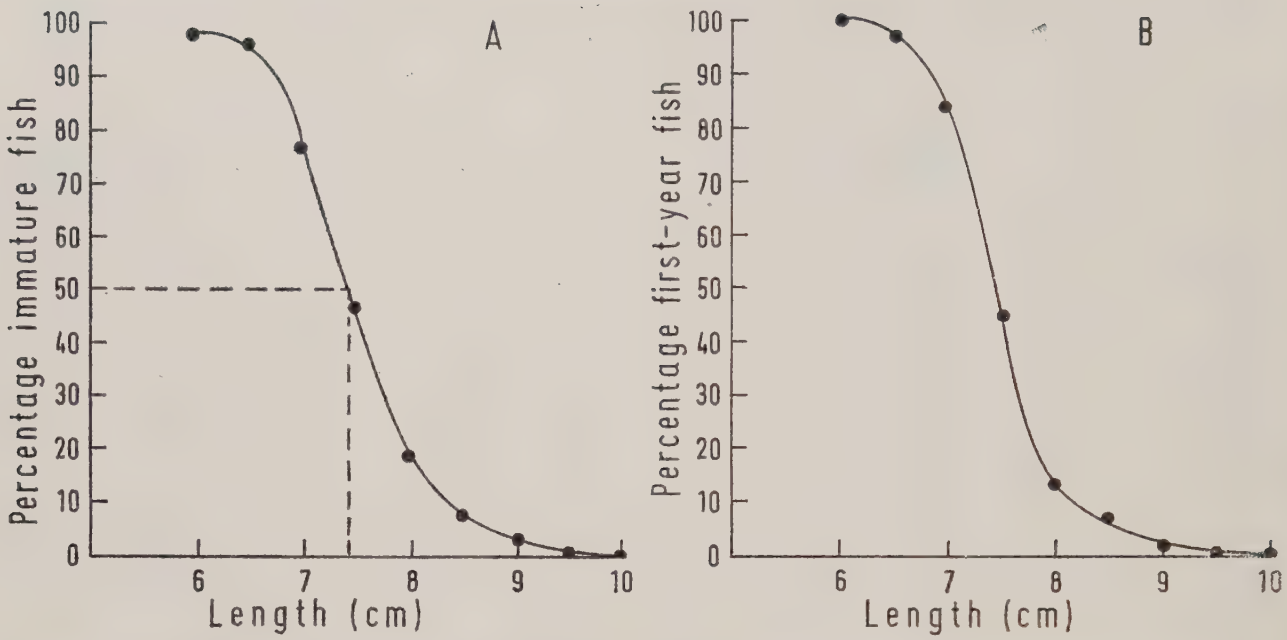


Figure 27 The relations between length of fish and A: the percentage of immature fish, and B: the percentage of first-year fish in the catches.

MINIMUM SIZE FOR MATURATION

It was evident in most seasons that the lower size range for fish showing signs of gonadal development beyond the immature phase lay somewhere within the 7.0–7.5 cm length groups. This length range normally represents a zone of overlap between the larger first-year and smaller second-year fish, and is generally rather sparsely represented in the catch. An average minimum length for first signs of gonadal development was thus determined using Burd's (1962) procedure for North Shields herring, which involved plotting for each season the proportion of immature fish in each half-centimetre length group. This produced a fairly symmetrical ogive from which the 50 per cent level was read off as an average minimum length. Table 22 shows that, with the exception of the 1967–68 season, the minimum length for first signs of gonadal development in the winter months ranged between 7.3 and 7.9 cm. The sex ratios and the percentages of first-year fish over the length range 6.0–10.0 cm inclusive (used in the maturity ogives) are also included in the table, to determine whether or not any relationship is involved between either of these and the minimum length for maturation. A correlation analysis shows no significant relationship between length and sex ratio, and only a suggestive one (P 0.05) between length and the proportion of first-year fish.

The average percentage of immature fish for the period 1958–1966 is shown in Figure 27, together with a comparable ogive showing the proportion of first-year fish over the same length range. The shapes and positions of these two curves are practically identical, which again suggests a possible link between age and minimum size for maturation. The numbers of first-year fish above 7.0 cm in the catch are usually low, which numerically restricts the overlap zone between large first-year and small second-year fish. This makes maturity analysis of the two age-groups over comparable length ranges difficult in an average season, and unfortunately the information from most seasons is not sufficient to critically examine this relationship. However, the 1967–68 season did provide enough material to examine in more detail the relationships between sex, age and maturation length; this information is summarized in Table 23. The results suggest that in males the average minimum size for maturation is virtually identical in first- and second-year fish (about 8.75 cm), but in the females no immature specimens were noted in any of the second-year fish down to the minimum size recorded for second-year females (8.0 cm). However, immature fish were very abundant over a comparable length range in first-year females, the minimum length for maturation in these fish being somewhat higher (9.1 cm) than in first- or second-year males. The female fish thus showed signs of gonadal development down to the minimum size for two-year-olds, but in their first year the onset of maturation was more critically determined by length, this also being the case for both first- and second-year males. However, these observations refer to a very limited time period (December and January) and the situation might subsequently change if some of the apparently immature winter fish showed further development later on. Furthermore, it does not necessarily follow that all the stage I/II and II fish recorded in the winter months will later complete the maturation cycle and spawn in the following summer.

It is also evident from this table that the proportions of different maturity stages in each sex and each age-group are not the same, and this may be age-influenced. First-year fish of both sexes show a much higher proportion of immatures (relatively less in males) than do second-year fish, and the latter show a greater proportion of stage II fish (relatively more in males). However, the age-influence may only act in terms of relative delay, i.e. for fish of a given size the older ones will show signs of more advanced development earlier in the year than the younger, confirming that the larger fish tend to mature earlier than the smaller ones.

It is of interest to note that samples taken by a research vessel in the Thames Estuary and near the Norfolk Banks in April 1960 showed fish within the 6.0–6.5 cm length groups actually in spawning condition or very advanced maturity stages. These very small spawning sprats have also been noted off the French coast (Forest 1950), and seem quite usual in the Black Sea, where the lower size limit falls in the 5.0 cm group (Aslanova 1954). The 'whitebait' spawners proved on examination to be first-year fish (with one winter ring), and it seems that in the southern North Sea, under special circumstances, the sprat can mature a year earlier than is normally the case.

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Appendix Table A Seasonal sub-area analysis of catch data (1958–1968)

Season	Vessels	Sub-area	Total number of landings	Total hours' fishing	Total catch (tons)	Catch per hour (tons)	Catch per landing (tons)
1958–59	40 foot pair-boats	Inner Wash	136	–	677	–	4.98
		Off Wells	112	–	513	–	4.58
1959–60	40 foot pair-boats	Inner Wash	397	656	1 602	2.44	4.04
		Inner Dowsing	66	131	211	1.61	3.20
	Hull seiners (1 pair)	Inner Wash	3	17	34	2.01	11.43
		Inner Dowsing	4	21	41	1.95	10.23
1960–61	40 foot pair-boats	Inner Wash	384	553	2 061	3.72	5.36
		Inner Dowsing	23	50	85	1.70	3.70
		Off Wells	8	13	37	2.85	4.63
1961–62	40 foot pair-boats	Boston Deep–Freeman Channel	14	35	80	2.29	5.74
		Inner Wash	474	1 109	2 357	2.12	4.97
1962–63	40 foot pair-boats	Inner Wash	321	740	1 407	1.90	4.38
		Inner Dowsing	7	20	18	0.92	2.64
	Grimsby seiners (i) pair trawl	Inner Wash	15	128	226	1.76	15.05
		Inner Dowsing	6	71	217	3.05	36.16
		Inner Silver Pit	5	29	52	1.79	10.42
	(ii) single-boat midwater trawl	Inner Wash	3	11	9	0.82	3.03
		Inner Dowsing	6	96	109	1.18	18.17
1963–64	40 foot pair-boats	Inner Wash	82	119	467	3.92	5.70
		Inner Dowsing	36	59	202	3.42	5.60
		Off Wells	87	136	516	3.79	5.93
	Grimsby seiners (i) pair trawl	Inner Wash	4	123	127	0.95	29.33
		Inner Dowsing	3	52	109	2.09	36.35
		Lincs. coast	5	104	198	1.90	39.26
		Humber Estuary	10	95	345	3.63	34.53
		Yorks. coast	3	52	98	1.88	32.66
	(ii) single-boat midwater trawl	Inner Wash	49	1 042	813	0.78	16.59
		Inner Dowsing	17	412	282	0.68	16.62
		Lincs. coast	31	868	613	0.70	19.77
		Humber Estuary	21	247	341	1.38	16.23
		Yorks. coast	9	218	190	0.87	21.09
1964–65	40 foot pair-boats	Inner Wash	103	312	850	2.72	8.25
		Lincs. coast	2	3	1	0.41	0.62
		Off Wells	32	68	158	2.32	4.92
	Grimsby seiners (i) pair trawl	Inner Wash	7	357	217	0.60	30.95
		Inner Dowsing	5	199	153	0.77	30.60
		Lincs. coast	7	193	173	0.90	24.80
	(ii) single-boat midwater trawl	Inner Wash	68	2 297	1 148	0.50	16.90
		Inner Dowsing	50	2 255	1 098	0.48	21.95
		Lincs. coast	75	2 040	838	0.41	11.15

Appendix Table A (continued)

Season	Vessels	Sub-area	Total number of landings	Total hours' fishing	Total catch (tons)	Catch per hour (tons)	Catch per landing (tons)
1965–66	40 foot pair-boats	Inner Wash	189	394	1 262	3.20	6.68
		Off Wells	2	4	6	1.62	3.25
	Grimsby seiners						
	(i) pair trawl	Inner Wash	4	122	213	1.74	53.20
		Inner Dowsing	4	142	70	0.49	17.50
	(ii) single-boat midwater trawl	Inner Wash	76	1 731	1 582	0.91	20.80
		Inner Dowsing	107	2 548	2 356	0.92	22.00
		Inner Silver Pit	24	526	650	1.23	27.10
		Lincs. coast	17	399	119	0.30	7.00
1966–67	40 foot pair-boats	Inner Wash	71	97	403	4.15	5.68
	Grimsby seiners (single-boat)	Inner Wash	44	1 806	742	0.41	16.87
1967–68	40 foot pair-boats	Inner Wash	153	163	1 388	8.51	9.07
		Inner Dowsing	7	14	52	3.69	7.38
		Lincs. coast	92	127	1 029	8.10	11.18
	Grimsby seiners (single-boat)	Inner Wash	72	398	2 269	5.70	31.51
		Inner Dowsing	43	366	1 168	3.19	27.17
		Inner Silver Pit	78	724	1 920	2.65	24.62
		Lincs. coast	12	182	278	1.52	23.13

Appendix Table B Summary of length/age distributions by year-classes (expressed in numbers of fish (thousands) per landing by 40 foot pair-boats)

Length (cm)	Year-class										$\bar{N}$
	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	
	1st year										
3.5								0.8	0.6	–	0.1
4.0		–		0.1		6.8	6.4	1.3	2.3	2.4	1.9
4.5		0.1		0.1		13.2	21.9	2.6	7.5	17.9	6.3
5.0	2.2	0.8	0.2	0.1		14.5	16.7	3.4	8.1	28.1	7.4
5.5	4.1	1.2	0.7	0.4		11.2	17.9	3.5	1.1	35.9	7.6
6.0	32.0	3.0	5.5	1.4		14.4	17.9	1.9	2.8	44.3	12.3
6.5	92.1	5.1	7.0	5.4	0.6	21.6	23.1	0.5	17.7	90.5	26.6
7.0	93.9	7.7	9.2	18.1	1.0	8.9	21.7		20.5	132.4	31.3
7.5	81.8	7.3	7.3	21.9	0.7	2.2	23.1		28.3	188.7	36.1
8.0	40.8	7.5	4.7	22.7			13.8			266.0	35.6
8.5	9.9		4.8	11.1						215.7	23.2
9.0			0.4	6.7						185.2	19.2
9.5				2.7						65.3	6.8
Total	356.8	32.7	39.8	90.7	2.3	92.8	162.5	14.0	88.9	1 272.4	
	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	
	2nd year										
6.5				0.3	0.6	0.3		1.1	3.6		0.6
7.0		1.2	0.7	2.2	4.6	10.4	5.6	5.8	4.7		3.5
7.5		12.0	2.0	9.8	27.8	9.1	19.9	65.2	62.5	6.6	21.5
8.0	3.1	86.9	8.2	31.7	102.7	9.7	113.0	129.9	160.4	19.1	65.5
8.5	14.2	115.5	15.7	69.5	53.5	24.8	140.8	115.1	91.2	143.2	64.4
9.0	27.7	103.7	35.7	113.2	37.7	10.7	93.4	121.9	15.4	103.0	66.2
9.5	38.9	59.9	36.6	73.4	30.7	12.6	50.9	106.4	15.5	43.7	46.9
10.0	45.2	41.7	38.9	43.3	34.3	15.0	26.1	71.3	–	42.5	35.8
10.5	33.9	24.5	26.7	27.6	34.3	15.8	19.9	54.0	–	44.4	28.1
11.0	13.4	14.7	15.2	19.4	33.6	9.2	11.7	40.4	8.5	35.6	20.2
11.5	4.1	4.7	6.4	11.7	20.1	3.9	7.9	34.4	–	24.0	11.7
12.0	0.4	3.1	2.6	7.0	14.1		3.5	20.1	1.9	15.0	6.8
12.5		0.6	1.0	3.1	5.6			6.1	2.7	15.0	3.4
13.0		0.2	0.1	1.3	2.0			3.8		3.6	1.1
13.5				0.1	0.2			1.9		1.2	0.3
Total	180.9	468.7	189.8	413.6	401.8	121.5	492.7	777.4	366.4	496.9	

Appendix Table B (continued)

Length (cm)	Year-class										$\bar{N}$
	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	
	3rd year										
7.0						1.2					0.1
7.5				2.2		2.5					0.5
8.0			0.7	5.6	8.3	3.5	2.3				2.0
8.5		1.9	6.6	2.9	12.8	4.6	9.4	4.3	6.0		4.9
9.0	2.1	1.5	28.6	7.2	16.1	30.9	14.0	4.9	72.0	10.2	18.8
9.5	7.1	10.0	56.8	10.1	11.5	45.2	26.9	12.8	116.2	–	29.7
10.0	46.8	14.2	70.6	11.6	10.4	41.1	47.4	11.7	120.7	4.8	41.9
10.5	65.9	12.6	62.4	6.1	9.0	35.6	43.9	17.5	70.7	7.2	40.1
11.0	51.4	10.9	51.1	8.0	7.8	37.2	23.7	10.3	16.9	5.4	22.3
11.5	29.1	6.7	28.3	6.6	7.2	34.8	24.0	7.4	19.6	7.8	17.2
12.0	19.1	3.1	20.8	9.3	8.2	35.4	15.2	10.1	11.4	2.4	13.5
12.5	8.3	3.0	9.5	6.3	7.6	39.0	22.2	9.5	10.8	1.8	11.8
13.0	2.6	3.1	6.6	5.3	7.7	39.0	19.6	8.0	10.7	10.2	11.3
13.5	1.8	2.2	5.4	2.1	3.7	23.5	10.2	6.0	5.6	4.2	6.5
14.0	1.3	1.9	3.0	1.2	1.1	8.2	4.1	2.6	6.9	2.4	3.3
14.5	1.0	0.6	0.7	0.1	0.4	2.9		0.7	4.0	0.6	1.1
15.0		0.1	0.1	0.1	0.2	0.4		0.1	1.1		0.2
15.5				–							
Total	236.5	71.8	351.6	84.7	112.0	385.0	262.9	105.9	472.6	57.0	
	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	
	4th year										
8.0					2.5						0.2
8.5				1.2	4.8	1.6					0.8
9.0				6.8	10.5	2.7	2.9				2.3
9.5			0.6	21.0	11.0	6.3	6.1				4.5
10.0		1.9	5.3	27.4	12.8	3.9	9.7	3.3			6.4
10.5	2.0	1.4	3.6	16.0	2.2	6.3	8.8	1.8		1.8	4.4
11.0	1.1	2.2	4.9	17.9	4.3	4.9	23.4	1.0	5.7	1.2	6.7
11.5	6.1	4.6	2.1	14.3	1.0	2.2	12.0	–	–	–	4.2
12.0	5.4	3.8	1.8	11.4	4.1	1.9	10.2	1.2	1.9	0.6	4.2
12.5	3.7	4.6	0.9	6.4	1.4	2.9	9.4	1.2	1.4	1.2	3.3
13.0	1.2	4.5	0.8	5.4	0.8	1.7	7.0	0.7	3.6	1.2	2.7
13.5	0.4	3.2	1.0	2.8	0.9	4.8	14.0	1.0		3.0	3.1
14.0	0.5	3.5	1.2	0.7	1.1	2.5	12.6	1.9		1.8	2.6
14.5	0.5	2.6	1.4	0.5	0.2	0.7	8.5	1.7		0.6	1.7
15.0	1.2	1.4	0.6	0.1	0.3	0.2	1.2	0.9		0.6	0.6
15.5	0.3	0.3	0.3	–	0.4	0.1		0.2			0.2
16.0			–								
Total	22.4	35.0	24.5	131.9	58.3	42.7	125.8	14.9	12.6	12.0	

Appendix Table B (continued)

Length (cm)	Year-class										$\bar{N}$
	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	
	5th year										
9.5					1.8	1.1					0.3
10.0			0.7	0.9	1.8	–		3.3			0.7
10.5			4.2	–	3.4	1.6		1.0			1.0
11.0			3.5	0.5	5.0	0.6		–	2.8		1.2
11.5	0.7		2.1	0.2	5.3	0.6	0.3	1.0	–		1.0
12.0	0.9		2.0	0.4	4.1	–	1.5	–	3.8		1.3
12.5	–		0.8	0.1	2.5	1.0	–	–			0.4
13.0	0.2		1.1	0.1	1.2	–	1.8	–		0.6	0.5
13.5	0.1	0.1	0.7	–	0.4	–		0.4		–	0.2
14.0	0.2	0.2	1.3	0.3	0.3	0.8		0.2		–	0.3
14.5	–	0.1	1.8	–	0.2			–		–	0.2
15.0	–	0.3	2.0	0.1	0.3			0.5		0.5	0.4
15.5	0.5	0.1	0.7					–			0.1
16.0			0.1					0.1			–
16.5			0.1								–
Total	2.6	0.8	21.1	2.6	26.3	5.7	3.6	6.5	6.6	1.1	

Appendix Table C Average catch data per season by classes of vessel

	Season	Number of landings	Total hours' fishing	Mean fishing time per trip (hours)	Total catch (tons)	Catch per hour (tons)	Catch per landing (tons)
Boston and Wells (40 foot pair-boats)	1958–59 to 1967–68	280	514	1.8	1 538	2.99	5.50
	1962–63 to 1967–68	197	376	1.9	1 293	3.44	6.55
Grimsby seiners							
(i) pair trawl	1962–63 to 1965–66	22	417	18.9	545	1.35	24.75
(ii) single-boat midwater trawl	1962–63 to 1967–68	134	3 028	22.6	2 758	0.91	20.60

Appendix Table D Monthly analysis of Wash sprat landings

		Number of landings	Total catch (tons)	Catch per hour (tons)	Catch per landing (tons)	Mean fishing time per trip (hours)
Boston, Wells and Thames 40 foot pair-boats	1958–59					
	December	2	4	–	2.02	–
(up to 8 pairs)	January	66	255	–	3.86	–
	February	162	893	–	5.51	–
	March	18	38	–	2.11	–
		248	1 190	–	4.80	–
(up to 12 pairs)	1959–60					
	October	2	1	–	0.75	–
	November	90	471	–	5.23	–
	December	118	433	–	3.67	–
	January	106	510	2.02	4.81	2.37
	February	123	324	1.42	2.63	1.85
	March	22	70	1.37	3.20	2.33
	April	2	4	–	1.87	–
		463	1 813	(1.17)*	3.91	(2.15)*
(up to 11 pairs)	1960–61					
	September	6	1	–	0.16	–
	October	18	49	1.19	2.74	2.30
	November	94	649	4.35	6.90	1.59
	December	99	543	4.12	5.49	1.33
	January	100	501	3.32	5.01	1.50
	February	83	378	2.90	4.55	1.57
	March	15	62	1.62	4.10	2.53
		415	2 183	3.50	5.26	1.50
(up to 14 pairs)	1961–62					
	October	10	12	0.56	1.16	2.08
	November	154	979	2.68	6.35	2.37
	December	137	593	1.85	4.33	2.33
	January	50	228	1.96	4.55	2.32
	February	51	250	2.08	4.95	2.38
	March	82	360	1.62	4.39	2.71
	April	4	15	1.52	3.67	2.40
		488	2 437	2.07	4.99	2.41

Appendix Table D (continued)

		Number of landings	Total catch (tons)	Catch per hour (tons)	Catch per landing (tons)	Mean fishing time per trip (hours)
(up to 12 pairs)	1962–63					
	October	4	3	–	0.75	–
	November	98	453	1.97	4.62	2.40
	December	59	247	1.47	4.18	2.84
	January	31	171	4.45	5.50	1.23
	February	101	382	1.52	3.78	2.48
	March	35	170	2.00	4.85	2.43
		328	1 426	1.85	4.34	2.35
Grimsby vessels (50–65 feet)						
(i) pair trawl (up to 2 pairs)	November	4	39	1.52	9.87	6.50
	December	10	82	0.58	8.20	14.02
	January	7	154	4.05	22.02	5.43
	February	5	210	2.88	42.04	14.60
		26	485	1.75	18.67	10.64
(ii) single vessel trawl (1 vessel)	March	7	113	1.10	16.08	14.56
Boston and Wells 40 foot pair-boats	1963–64					
	November	35	212	3.57	6.07	1.70
(up to 6 pairs)	December	79	435	3.06	5.50	1.80
	January	47	314	4.40	6.68	1.52
	February	44	224	3.68	5.08	1.38
		205	1 185	3.54	5.78	1.63
Grimsby vessels (50–65 feet)						
(i) pair trawl (1 pair)	December	3	81	1.01	26.96	26.70
	January	7	271	1.75	38.76	22.15
	February	11	381	3.31	34.65	10.45
	March	4	134	1.76	33.52	18.99
		25	867	2.03	34.70	17.05

Appendix Table D (continued)

		Number of landings	Total catch (tons)	Catch per hour (tons)	Catch per landing (tons)	Mean fishing time per trip (hours)
(ii) single vessel trawl (up to 7 vessels)	November	11	129	1.45	11.72	8.06
	December	30	466	0.68	15.53	22.84
	January	38	810	0.82	21.31	25.84
	February	32	561	1.08	17.54	16.25
	March	16	264	0.57	16.48	28.67
	April	3	18	0.23	5.95	25.87
		130	2 248	0.80	17.29	21.61
Boston and Wells 40 foot pair-boats	1964–65					
	November	44	294	3.62	6.68	1.9
(up to 4 pairs)	December	35	219	2.48	6.25	2.5
	January	35	297	2.35	8.47	3.6
	February	23	199	1.76	8.66	4.9
		137	1 009	2.51	7.36	2.9
Grimsby vessels (i) pair trawl (up to 2 pairs)	November	1	61	0.51	61.00	120.0
	December	7	105	0.51	14.98	29.3
	January	7	248	0.95	35.40	37.3
	February	4	129	0.79	32.39	40.8
		19	543	0.72	28.60	39.4
(ii) single vessel trawl (up to 15 vessels)	November	24	415	0.59	17.28	29.4
	December	41	594	0.39	14.49	37.1
	January	57	1 147	0.58	20.13	34.5
	February	50	759	0.41	15.18	36.9
	March	22	185	0.32	8.43	26.5
		194	3 100	0.47	15.98	34.1
Boston and Wells 40 foot pair-boats	1965–66					
	November	2	6	1.62	3.25	2.0
(up to 10 pairs)	December	79	518	4.09	6.55	2.1
	January	80	568	3.34	7.09	2.1
	February	30	177	2.29	5.88	2.6
		191	1 269	3.05	6.64	2.2

Appendix Table D (continued)

		Number of landings	Total catch (tons)	Catch per hour (tons)	Catch per landing (tons)	Mean fishing time per trip (hours)
Grimsby vessels						
(i) pair trawl	November	1	39	1.31	39.00	30.0
(up to 2 pairs)	December	3	173	1.88	57.76	30.7
	January	4	70	0.49	17.51	35.5
		8	282	1.07	35.35	33.0
(ii) single vessel trawl	November	10	198	1.05	19.84	18.9
(up to 22 vessels)	December	79	1 987	1.42	25.16	17.8
	January	77	1 620	0.82	21.04	25.6
	February	44	751	0.59	17.06	28.6
	March**	14	150	0.46	10.73	23.1
		224	4 706	0.91	21.01	23.0
Boston and Wells	1966–67					
40 foot pair-boats						
	November	8	40	3.17	4.95	1.56
(up to 4 pairs)	December	19	58	1.52	3.06	2.07
	January	30	178	5.27	5.93	1.12
	February	14	128	8.77	9.13	1.08
		71	404	4.15	5.68	1.40
Grimsby vessels						
single vessel trawl	November	24	506	0.46	21.09	46.0
(up to 16 vessels)	December	20	236	0.33	11.81	35.0
		44	742	0.41	16.85	41.0
Boston and Wells	1967–68					
40 foot pair-boats						
	November	3	32	27.65	10.75	0.4
(up to 8 pairs)	December	59	526	11.35	8.90	0.8
	January	62	690	7.60	11.15	1.5
	February	89	873	7.60	9.80	1.3
	March	39	346	6.80	8.90	1.3
		252	2 467	8.10	9.80	1.2

Appendix Table D (continued)

		Number of landings	Total catch (tons)	Catch per hour (tons)	Catch per landing (tons)	Mean fishing time per trip (hours)
Grimsby vessels single vessel trawl						
(up to 19 vessels)	December	62	2 004	6.00	32.30	5.4
	January	96	2 491	3.00	25.95	8.6
	February	37	894	1.50	24.15	16.1
	March	10	246	0.65	24.55	37.8
		205	3 631	2.65	27.50	10.4

* Part season only.
** In March many landings were of herring only or sprats and herring; only landings of sprats are included here.

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